PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by V. Mawson

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Hobart

Tasmania

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 136

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TASMANIA

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TRAPPING AND RELOCATING SEALS FROM SALMONID FISH FARMS IN TASMANIA, 1990–2000: WAS IT A SUCCESS?

by F. Hume, D. Pemberton, R. Gales, N. Brothers and M. Greenwood

(with three tables and five text-figures)

HUME, F., PEMBERTON, D., GALES, R., BROTHERS, N. & GREENWOOD, M., 2002 (31:xii): Trapping and relocating seals from salmonid fish farms in Tasmania, 1990–2000: was it a success? *Papers and Proceedings of the Royal Society of Tasmania* 136: 1–6. ISSN 0080–4703. Marine Conservation Unit, Nature Conservation Branch, Department of Primary Industries, Water and Environment, GPO Box 44, Hobart, Tasmania 7001, Australia (FH, RG*, NB, MG); Tasmanian Museum and Art Gallery, GPO Box 1164M, Hobart, Tasmania 7001, Australia (DP). * Author for correspondence.

In an effort to reduce the impact of seals on fish farms, the trapping and relocation of seals at Tasmanian salmonid farms began in 1990. To the end of May 2000, 353 identified individual seals had been trapped in 672 capture events. Most were non-breeding male Australian fur seals (*Arctocephalus pusillus doriferus*). The number of seals captured increased (from four in 1990 to a peak of 164 in 1998) with the size and extent of the farms, and an increase in salmon production from 55 tonnes in 1986/87 to almost 10 000 tonnes in 1999/2000. Of 586 capture events 52% were of seals that had been captured more than once. When seals are recaptured following trapping and relocation, this occurs on average 25 days after capture. Capture-mark-recapture calculations show that many seals in the vicinity of fish farms are not 'trappable', suggesting that trapping is only effective for certain individuals. Some individuals are recaptured many times, reflecting the predisposition of some individuals to be captured ('trap-happy'). Interaction is seasonal, with most seals trapped during winter, between May and September. The assessment of trends in capture rates is problematic, due to the lack of capture effort information from the farms. A further confounding factor has been the change in management practice both between farms and over time, as the use of predator nets has become more widespread. Two seals trapped at fish farms and fitted with satellite transmitters before relocation have either not returned to the farm or returned to the vicinity of farms and not interacted with them, although on one occasion the individual was trapped. The effectiveness of the relocation program as a management tool to reduce seal interactions cannot be quantified from the relocation data *per se*, but relocation does not stop seals interacting with farms.

Key Words: seals, trapping, relocation, recapture, fish farms, Australian fur seal, New Zealand fur seal, salmon production, predator nets, Tasmania.

INTRODUCTION

The concentration of abundant potential food within fish farms is a major attraction to piscivorous predators and results in a significant management problem for fish farmers (Ross 1988, Pemberton *et al.* 1991). In the northern and southern hemisphere seals are the most prevalent predators at fish farms (Hawkins 1985, Ross 1988, Pemberton & Shaughnessy 1993). The Australian fur seal (*Arctocephalus pusillus doriferus*) is the main predator interacting with salmonid fish farms in Tasmania (Pemberton *et al.* 1991).

Seal interactions result in the mortality of fish through direct consumption and stress to fish by attacks (Howell & Munford 1991). Anecdotal evidence suggests that this stress prevents fish from feeding efficiently and can reduce growth rates (P. Warner & S. Tideman, pers. comm.). Seal attacks may also result in damaged nets and escape of fish; net repair increases production costs. In the case of southern hemisphere salmonid fish farms, escaped fish become feral predators in marine systems (pers. obs.). In the northern hemisphere, where salmonids occur naturally, escaped salmon can interbreed with wild fish and thereby affect the genetic integrity of the natural populations (Fleming & Gross 1993).

Since marine fish farms began operations in Tasmania in the early 1980s there has been a considerable increase in both the number and extent of fish farms. These increases have been met, not surprisingly, with an increase in the number of seal interactions. In Tasmania ten companies currently operate 26 fish farms growing Atlantic salmon (*Salmo salar)* and Rainbow trout (*S. gairdneri).* Production from these farms has increased to an annual harvest exceeding 9000 tonnes of fish from an area of approximately 500 hectares (source: Department of Primary Industries, Water and Environment (DPIWE)).

MANAGEMENT OF SEAL INTERACTIONS AT TASMANIAN FISH FARMS

Since 1985, the Tasmanian Parks and Wildlife Service (TASPAWS) has been involved with seals at fish farms, due to its legal responsibility for the protection of seals in Tasmanian waters. TASPAWS has since provided advice and assistance in the trialling of various techniques to deter seals from attacking fish pens (Pemberton 1989, Pemberton & Shaughnessy 1993).

Shooting (to scare or kill) was permitted in Tasmania (Section 35(1) *Tasmanian National Parks and Wildlife Act* 1970) as a method of seal control from 1987–95. Permits to shoot were issued under 'exceptional' circumstances, such as if a seal breached the protection systems, and on the provision that anti-predator nets be installed as quickly as possible. This policy attracted much criticism, but was seen at the time to be a temporary method to sustain farm production while protection barriers were improved.

As well as shooting, other deterrents, including pursuit with boats, seal crackers, lights, acoustic scarers and conditioned food aversion, have all been tried on fish farms in southeastern Tasmania (Pemberton & Shaughnessy

1993). None of these methods provided long-term effective mitigation of seal interactions with the farms. Predators such as seals are highly mobile, and localised persecution has only a short-term benefit because immigration is likely to replace those animals removed or killed (Howell & Munford 1991). Additionally, of those seals that are scared from the lease, many return when the deterrent is relaxed (Pemberton & Shaughnessy 1993).

The use of a predator net surrounding the stock net, forming a physical barrier between predators and the fish cage is the most effective method of predator control (Arnold 1992, Pemberton & Shaughnessy 1993). The trapping and relocation of seals was introduced as a temporary method of seal control in 1990 to assist farmers while they trialled and improved the design of predator nets. After nine years of trapping and relocating and following consultation with the Parks and Wildlife Service and fish farmers in mid-1998 it was agreed that this process be phased out by the end of 1998. Subsequent permits to continue to trap and relocate seals post-1998 were issued when 'exceptional circumstances' occurred, such as the need to drop predator nets because of reduced water flows or difficulty obtaining sufficient and optimal predator netting. To date (late 2001) permits are issued for trapping of seals after assessment and consultation between DPIWE officers and the fish farmer concerned.

This paper reports on the trapping and relocation of seals from fish farms conducted by the Nature Conservation Branch (NCB (DPIWE), formerly part of TASPAWS) from 1990–2000. The aims were to assess the efficacy of removal and relocation of seals as a primary mitigation method to protect fish farms from seal interactions. Aspects considered in this assessment included the type of seal trapped at farms, the likelihood of the return to the farm following relocation and the time elapsed between relocation and return.

METHODS

Trapping and relocation of seals began in 1990 at one farm and has since spread to all fish farms operating in southeastern Tasmania. The traps are c. 3 m x 3 m x 2 m in size and are made from reinforced steel mesh with a recommended mesh size of 5 cm x 5 cm. Attached floats keep the top 40 cm of the trap above the water and traps are either placed on the outer perimeter of the farm lease or adjacent to the pens being impacted by the seals. A sliding trap-door is triggered through a line which is baited with a dead salmon. Additional dead fish are sometimes attached around the cage to act as an added attractant. Traps are checked throughout the day and intermittently at night. Once a seal is captured, the designated relocation officer is notified and the seal is transferred into a transport cage and then towed to shore and lifted out of the water. Trapped seals are then transferred into the 'relocation trailer' and weighed on electronic scales before being taken to a veterinary clinic for assessment and final transport to the release site. Animal ethics regulations specify that seals are to be removed from the trap in the water within six hours and that the seal must be relocated within 48 hours of capture.

Since 1990, the method of marking seals has varied and has included paint marks, tagging, freeze-branding and the use of microchips (subdermal transponders). In the initial years of the program, all new seals were anaesthetised and then tagged or freeze-branded. A veterinarian examined all seals for general health, blood was taken for haematological, biochemical, toxicological and genetic studies; standard measurements (length and girth) were recorded. Since 1997, with the introduction of microchipping, which is a quick and efficient method of marking (and can be done by the person responsible for relocating), not all seals have received veterinary assessments. Seals (30 annually and those judged to be in poor health) which are bled for disease sampling are anaesthetised.

From 1990 to 1993, TASPAWS financed the trapping and relocation program. However, since 1994, the farms have been billed as the Service is no longer able to bear the costs. The initial cost was $400 per seal and has since increased to $500 per seal or $600 if two seals are captured at the same farm at the one time.

The trapping and relocation data provided here were collected from 1990 until 30 May 2000, unless otherwise stated. Accordingly, the 1990 data and 2000 data do not constitute information for full years. Data relate to seals handled by TASPAWS personnel. Under some circumstances fish farmers illegally trapped and relocated seals themselves. We do not have access to those data.

The seals were relocated to several sites up to 600 km from the capture site (fig. 1). Some sites were used more frequently than others.

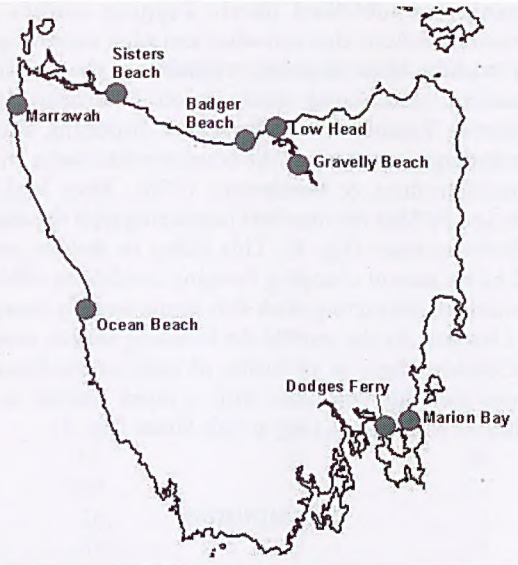
A capture-mark-recapture analysis (Caughley 1977) was carried out to calculate the total number of seals in the vicinity of a particular farm. One farm was chosen, based on the large sample marked (87 individuals at *time 1*, 1997) and recaptured (45 individuals at *time 2* in 1998). The Peterson Index (the estimate of population size) was the model used to estimate the total population at *time 2* (Caughley 1977).

RESULTS

Six hundred and seventy-two seals have been captured at fish farms since 1990 (table 1). Where identified, all captures were of male Australian fur seals, except for one leopard seal (*Hydrurga leptonyx*) captured in 1996 and one New Zealand fur seal (*Arctocephalus forsteri*) in 1998. While most are undoubtably Australian fur seals, recent indications are that New Zealand fur seals could also be involved more commonly. Identification of the species is problematic (Goldsworthy *et al.* 1997) and the data presented here possibly include some incorrect identification. The number of seals captured steadily increased over time, reaching a peak in 1998. Substantially fewer seals were trapped in 1999 followed by an increase in 2000 (table 1). The extent of farm production has also increased substantially between 1990 and 2000 (fig. 2).

The weights of 257 captured seals ranged from 45 kg to 385 kg with a mean of 147 kg (s.d. 66 kg) (fig. 3). Whilst body mass is an imprecise estimator of age, extensive field observations show that it is the larger (c. > 200 kg) male fur seals which are more numerous at the breeding colonies. Using an arbitrary mass of 200 kg to indicate the difference between breeders and non-breeders, the trapped population was likely comprised mainly of non-breeding animals (78% of weights were less than 200 kg).

From the 672 captures, the individual identity was obtained in 586 cases, and 353 different individuals were recorded (table 1). Of the 586 identified captures, 303 (52%) were of seals that had been trapped previously (table



Relocation Site	Number released	Number recorded back at fish farms	% recorded back at fish farms
Badger Beach	164	87	53
Gravelly Beach	129	79	61
Low Head	55	31	56
Marrawah	21	10	48
Sisters Beach	9	3	33
Ocean Beach	5	4	80
Marion Bay	4	3	75
Dodges Ferry	3	1	33
Total	390	218	56

FIG. 1 — Map of Tasmania showing major relocation sites (where three or more releases have occurred), 1999–2000. Numbers of seals released and recaptured also shown.

TABLE 1
Numbers of trapped and relocated seals from fish farms in Tasmania, 1990–2000

Year	All captures	Identified captures	Identified individuals	New* individuals	Captures of new* individuals
1990†	4	2	1	1	1
1991	11	10	5	5	10
1992	21	14	9	9	14
1993	36	34	22	22	34
1994	45	39	22	16	29
1995	23	16	7	3	3
1996	37	25	14	10	15
1997	164	125	68	62	110
1998	164	156	80	56	85
1999	59	59	53	36	37
2000†	108	106	72	49	60
Total	672	586	353		

* Seals captured for the first time.
† Data from incomplete calendar years (see Methods).

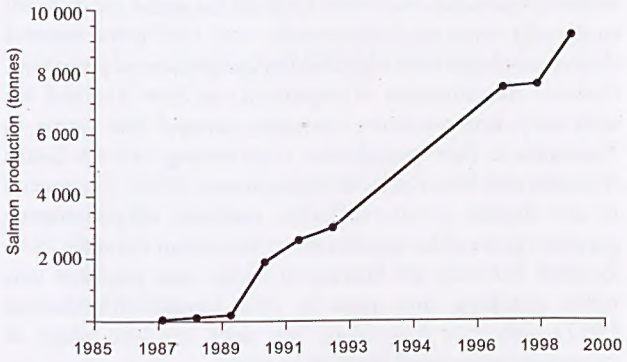


FIG. 2 — Atlantic salmon production (tonnes) at Tasmanian fish farms, 1987–1999 (information supplied by DPIWE).

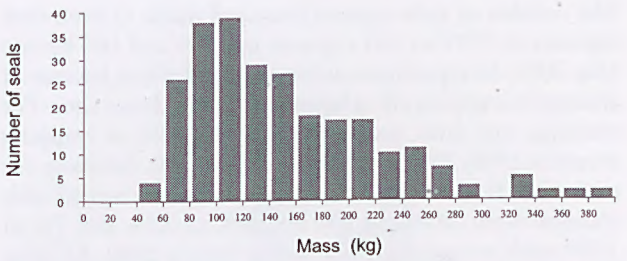


FIG. 3 — Body mass of male Australian fur seals trapped at fish farms in Tasmania, 1990–2000 (n = 253).

2). While most seals (66%) are captured only once in a year, some are captured twice (17%) or three times (10%). A small number of seals (7%) are caught more frequently; the maximum recorded was two individuals caught more than ten times in one year. Most seals are captured and/or recaptured in only one year although a small number return in following years (fig. 4). Not all seals returned in consecutive years. One individual, for example, was captured three times in 1994, once in 1995 and then not recaptured until 1998, when he was captured once. The number of captures and recaptures has varied over time, partly because the capture effort by farmers has changed over time. For example, in 1999 extensive effort to protect fish pens via double netting reduced trapping effort and capture rates.

Captured seals were relocated to a range of sites on the east, north and west coasts of Tasmania (fig. 1). Seals have returned from all major relocation sites. Most seals (74%) were recaptured at the same farm as their initial capture (table 3).

While the time between recaptures is highly variable, on average the seals take 25.2 days (s.d. 22.1) before they are recaptured. In 1998, Badger Head was the major release site, the mean time till recapture was 25.2 days (s.d. = 21.4) covering a minimum distance of 16 km each day. The fastest return from Badger Head was four days, a minimum distance travelled of 100 km per day. The data show that

the presence of seals at fish farms is a seasonal occurrence, with a consistent peak in the months from May to September (fig. 5).

The mark-recapture analysis gave an estimate of 113 (s.d. = 10.7) individuals at *time 2* (in 1998) for the farm where 45 individuals were captured (in 1987). This suggests that fewer than half of the animals foraging in the vicinity of the farm were captured.

DISCUSSION

Species of Seal

Three species of seal have been trapped at fish farms in Tasmania: Australian fur seals, one leopard seal and one New Zealand fur seal. From its inception in 1990, the trapping and relocation of seals from salmonid farms was used as a method of predator control, resulting in the capture of at least 586 individuals. Most of the trapped seals were identified as Australian fur seals with 73% of weighed animals classified as non-breeding animals. These data do not reflect the true proportion of fur seal species captured, because the two species commonly found in Tasmanian waters (Australian and New Zealand fur seals) are difficult to identify correctly (Goldsworthy *et al.* 1997), and some of the captured seals were identified by inexperienced personnel. Correct identification is important, as New Zealand fur seals may become more common around fish farms in Tasmania as their population is increasing in both South Australia and New Zealand (Shaughnessy 1999). The species is also known to use different methods of penetrating predator protection systems from Australian fur seals. New Zealand fur seals are known to climb over predator nets when attacking tuna pens in Port Lincoln (Pemberton 1997), whereas Australian fur seals are less adept at manoeuvring around pens and cages.

The Number of Seals Captured

The number of seals trapped increased (table 1) from four captures in 1990 to 164 captures in 1998 and 108 by late May 2000. Interpretation of this trend is difficult because of changes in trapping effort between farms and over time. For example, one farm was responsible for 30% of trapping events in 1998, 29% in 1999 and 5% in 2000. Similarly, for two other farms the relative proportions of trapped seals changed from 28% and 6% in 1998, to 22% and 2% in 1999, with no seals caught at either farm in 2000. All three of these farms are managed by the same company, which restricted trapping from 1999 when new predator nets were introduced.

Another complicating factor is the concomitant increase in the size of the farms as shown by the tonnage produced (fig. 2). Seals prey on fish in the pens and wild fish which forage in the vicinity of the pens. Consequently, as the farm size increases, so their attraction to seals increases.

The seasonality of seal attacks by Australian fur seals at fish farms in southern Tasmania is probably a result of both the seasonal movements of the species and the location of food. Satellite tracking studies indicate that breeding females from colonies in eastern Bass Strait remain in Bass Strait throughout the year and females from Reid Rocks (western Bass Strait) frequent waters off the west coast of Tasmania (unpublished data). Tagging studies and observations indicate that sub-adult and adult males disperse more widely than females, exploiting the southern Tasmanian continental shelf region (Warneke 1975, Brothers & Pemberton 1990). These dispersing animals arrive in large numbers at the southern haul-outs in late summer (Brothers & Pemberton 1990). They feed and moult, and by May the numbers interacting with the inshore fish farms increase (fig. 5). This influx to inshore waters could be because of changing foraging conditions offshore. The number interacting with fish farms steadily increases until October. At the start of the breeding season, towards mid-October, there is an influx of seals to the breeding colonies and this coincides with a rapid decline in the number of seals interacting at fish farms (fig. 5).

Recaptures

Fifty-two percent of the total identified captures, since 1990, are recaptures (table 2). In 1997, 48 new individuals accounted for 76% of the recaptures; the remaining 15 individuals (24%) had been captured in previous seasons. In 1998, however, 29 new individuals accounted for 29% of the recaptures and 71 individuals from previous seasons made up 71% of the recaptures. This shift may be explained by an increased trapping effort, instigated in 1997, which would increase the probability of capture for those animals new to the food source in that year. This recapture pattern probably reflects the ability of the seals to exploit a new resource.

Most seals are caught only once, although 17% of seals have been caught twice and 10% caught three times. The capture frequency of individuals may increase over time with continued trapping and industry expansion. As more seals discover this predictable food source, there is an increased chance of recapturing individuals which acquire a taste for salmonids in the pens and traps, and the wild fish attracted to the pens. Most seals that are trapped at the farms are trapped in only one year (fig. 4); 40% are caught in following years, generally in consecutive years, but some seals are not recaptured for a year or more. Many are not retrapped and, if this is used as a measure of success, trapping and relocation does reduce the number of seals close to a farm for a period of time.

Some seals are trapped repeatedly in the same year or repeatedly in following years. An example of this is one individual captured nine times in 1997, 16 times in 1998 and 14 times in 2000 (not trapped in 1999). This individual and the other multiple-captured seals reflect a trapping behaviour shown by many mammals and termed 'trap-happy' (Caughley 1977). In most mammal studies based on trapping individuals there is also a portion of the population that is trapped less frequently and termed 'trap-shy'. Another portion of the population is 'untrappable'. In the case of the fish farms, the 'trap-shy' and 'untrappable' animals are not controlled by the trapping management practice. 'Trap-happy' individuals are sometimes perceived as rogues and implicated in the damage to pens and fish. This is conjecture as a trapping event shows only that the animal is trappable and in the vicinity of the fish pens.

The total number of animals interacting with the fish farm includes both the trapped sample and untrapped sample. Sufficient data existed to calculate the total population for one farm; this showed that 45 seals were

TABLE 2
Numbers of recaptured seals per year from fish farms in Tasmania, 1990–2000

Year	All recaptures (*n*)	Recaptures as % of identified captures	New recaptures (*n*)	New recaptures (%)	Recaptures from previous seasons (*n*)	Previous seasons recaptures (%)
1990	0	0	0	0	0	0
1991	5	50	5	100	0	0
1992	5	36	5	100	0	0
1993	12	35	12	100	0	0
1994	23	59	13	57	10	43
1995	13	81	0	0	13	100
1996	14	56	5	36	10	71
1997	63	50	48	76	15	24
1998	100	61	29	29	71	71
1999	23	39	1	4	22	96
2000	57	53	11	19	46	81
Total	303	52	129			

TABLE 3
The number and location of recaptures of seals at fish farms in Tasmania, 1990–98

	Recapture farm†									
Initial capture farm*	K	L	H	J	I	G	E	C	B	A
K (211)	84 (84%)		1	2	1	1	1	8	1	1
L (1)	1									
H (65)			16 (76%)			2		3		
J (21)				2	1			1		
I (6)										
G (62)	1		5			35 (85%)				
E (2)										
C (90)	4		6	2		1		30 (65%)	2	1
B (11)	2					1		10		
A (9)										2

* Total captures in brackets.
† Codes used to protect farm identity.

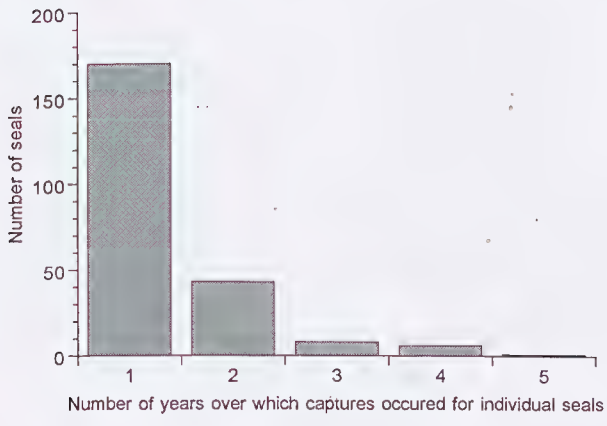


FIG. 4 — Number of seals trapped in one year, or in years subsequent to initial capture, at fish farms in Tasmania, 1990–2000.

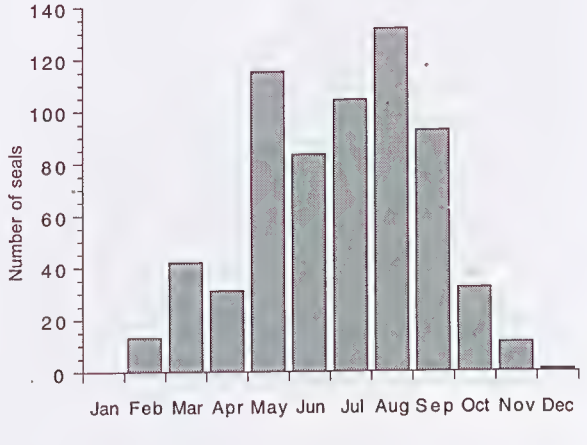


FIG. 5 — Number of seals trapped each month at fish farms in Tasmania, 1990–2000.

caught but the population was estimated to be 113. There are many assumptions associated with this type of calculation, for example, the need for marked animals to be selected at random, the recapture sample being random with regard to whether animals are marked or unmarked, and the need for the population to be closed (Caughley 1977). In this study, as in many other wild animal trapping programs, these assumptions may have been violated to some extent. Nonetheless, it is apparent that many seals are not caught and that the size of the population interacting with the fish farm is considerably greater than the number caught, hence a limitation of trapping as a management option.

Behaviour after Release

Many relocation sites have been used since 1990, and seals have returned from all major relocation sites (fig. 1). It is evident that, regardless of where seals are relocated, they are able to return, and they can return in a similar time from any of the relocation sites. The time between recaptures is, on average, 25 days which means that the farm has a significant period without the presence of that particular seal, a factor some farmers consider sufficient to justify relocation as a management tool.

Seals that are recaptured mostly return to the site of original capture, showing fidelity to one particular farm for up to five years (table 3). This behaviour is also shown by Australian fur seals which have been satellite tracked from the breeding colonies in Bass Strait. Individuals from Tenth Island routinely frequented particular areas (unpublished data). It appears, therefore, that individual seals learn about predictable food sources and utilise them both within and between years.

CONCLUSION

This study demonstrates that seal relocation is not effective as a primary protection method to protect fish farms from seal interactions. Effective predator nets should be used whenever seal interactions are a problem. One of the limitations of the use of predator nets is the cost of net management, particularly in summers when warm water results in increase growth of fouling organisms on the net and resultant loss of water flow, which affects fish health. The strong seasonal nature of seal interactions suggests that in the warmer months only, when there are fewer seals and more fouling of nets, relocation could be considered as a part of a management strategy when 'exceptional circumstances' of individual seal interactions are encountered. In winter and spring, when seal interactions increase, appropriate, effective predator nets are essential at all times. The management of nets at this time is easier, because fouling is less of an issue. This rotation of predator control methods, as well as further investigation into more effective mitigation techniques, will help to reduce the numbers of seals transported and assist in more efficient and cost-effective farm management.

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THE SIGNIFICANCE OF A NEW LOCALITY FOR *MONOGRAPTUS THOMASI* (EARLY DEVONIAN) SOUTHWEST OF BEACONSFIELD, TASMANIA, AND OF THE CORN HILL FORMATION

by R. B. Rickards, P. B. Hills, M. R. Banks and G. MacDonald

(with one plate, three text-figures and one appendix)

Rickards, R.B., Hills, P.B., Banks, M.R. & MacDonald, G., 2002 (31:xii): The significance of a new locality for *Monograptus thomasi* (Early Devonian) southwest of Beaconsfield, Tasmania, and of the Corn Hill Formation. *Papers and Proceedings of the Royal Society of Tasmania* 136: 7–16. ISSN 0080–4703. Department of Earth Sciences, University of Cambridge, Cambridge CB2 3AP, UK (RBR); Beaconsfield Mine Joint Venture, 5 West Street, Beaconsfield, Tasmania 7270, Australia (PBH, GM); and School of Earth Sciences, University of Tasmania, GPO Box 252-79, Hobart, Tasmania 7001, Australia (MRB*). *Author for correspondence.

Monograptus thomasi, Early Devonian, occurs west of Cabbage Tree Hill, Beaconsfield, Tasmania, in rocks previously mapped as Cambrian. The occurrence constrains the location of a basal thrust considered to be a conduit for Late Devonian gold mineralisation. The Corn Hill Formation, which contains the graptolite, is significant in regional stratigraphic, palaeogeographic, structural and tectonic models.

Key Words: *Monograptus*, Devonian stratigraphic relationships, Tasmania, thrust fault, gold mineralisation.

INTRODUCTION

The discovery in December 2000 of Early Devonian graptolites in Blyth Creek, 2 km southwest of Beaconsfield (146°48'E, 41°13'S) and some 5 km NNW of an earlier discovery of the same species by Banks & Rickards (1989) (fig. 1) is significant at both a local and regional scale. The discovery confirms the recent reassignment of the rocks containing the fossils, previously considered Cambrian in age (Green 1959, Gee & Legge 1971, 1979), to the Devonian. In so doing, it constrains the location of a basal thrust considered to be a conduit for later Devonian gold-bearing mineralising fluids, which gave rise to the Tasmania Reef deposit at Beaconsfield. In a regional sense, the graptolites provide further solid evidence for incorporation of the fossiliferous rocks into the framework of the geology of northeastern Tasmania, which is currently being revisited.

The material collected and described in this paper was dug from bedrock exposed in two outcrops 5 m apart in the bed of Blyth Creek. The creek has cut through thin Tertiary regolith into bedrock over a length of about 500 m.The incision reveals rocks similar to those which crop out on Leviathan Hill immediately to the northeast. Sampling conditions could best be described as adverse, as Blyth Creek drains a significant spring discharging in the order of 5–6 Ml/day and the sampling site is constantly beneath a metre of fast-flowing water. Although no outcrop occurs in the area of the spring, it is reasonably assumed that the water flows from a sinkhole in the Flowery Gully Limestone, as travertine-like deposits occur around the edges of the spring. The limestone, of Early Ordovician age (Kennedy 1971), crops out at several localities in the district and occurs stratigraphically above the Denison Group siliciclastics which crop out on Peaked Hill immediately west of the spring and generally dip east.

STRATIGRAPHY

Hills (1982) defined the Corn Hill beds, hereafter (Appendix) redefined as the Corn Hill Formation, of Devonian age in the vicinity of Bulls Road, east of Flowery Gully, and interpreted them as a series of turbidite deposits having affinities with the Mathinna Group of northeastern Tasmania. At Flowery Gully, the Corn Hill Formation disconformably overlies fine-grained, in places flaser-bedded, quartz siltstones, the Johnston Creek Siltstone (Hills 1982) of Late Ordovician or Early Silurian age (Kennedy 1971, Hills 1982, Kennedy & Hills 1989: 212–213). The Corn Hill Formation, over an approximate thickness of 600 m, consists largely of foliated micaceous shaley siltstones with lesser quartzwacke sandstones interbedded with graded quartzwacke sandstone-siltstone-shale units of turbiditic style, particularly along Bulls Road, southwest of Beaconsfield. At this type locality, the Corn Hill Formation shows characteristic alternation of shale and sub-greywacke over intervals of a metre (Hills 1982) and exhibits flute casts (pl. 1A), cross-lamination, slump folds and load cast features similar to those illustrated by Powell *et al.* (1993: fig. 12c) from the Scamander Slate and Quartzite (Scamander Formation) of Walker (1957) at Upper Scamander. Hills (1982) measured 28 of these features to derive a palaeocurrent direction towards the ENE, consistent with the common mean direction of 059° derived by Powell *et al.* (1993) for the Mathinna Supergroup in the Bridport–Bellingham area (fig. 2). The top of the Corn Hill Formation is truncated by Devonian thrusting. A Pragian age was assigned to the formation by Hills (1982) on the basis of a diverse fauna including the pelecypods *Actinopteria meridionalis* and *Praecardium* sp., the dacryoconarid *Styliolina minuta* and various cephalopods, trilobites and plant fragments. Banks & Rickards (1989) recorded *Monograptus thomasi* at the same location on Bulls Road and confirmed the Pragian age for the formation. A plant, cf. *Baragwanathia*, is associated with *M. thomasi* at that locality (Baillie *et al.* 1989: 236).

Mapping in recent years by geologists from the Beaconsfield Gold Mine, in particular MacDonald (1999), suggested that the Corn Hill Formation was extensive along strike. The formation was considered to encompass the rocks at Leviathan Hill which Green (1959) defined as the Ilfracombe Slate and considered as of Cambrian age on lithological grounds. This conclusion was not challenged when Gee & Legge (1971, 1979) invoked a model of

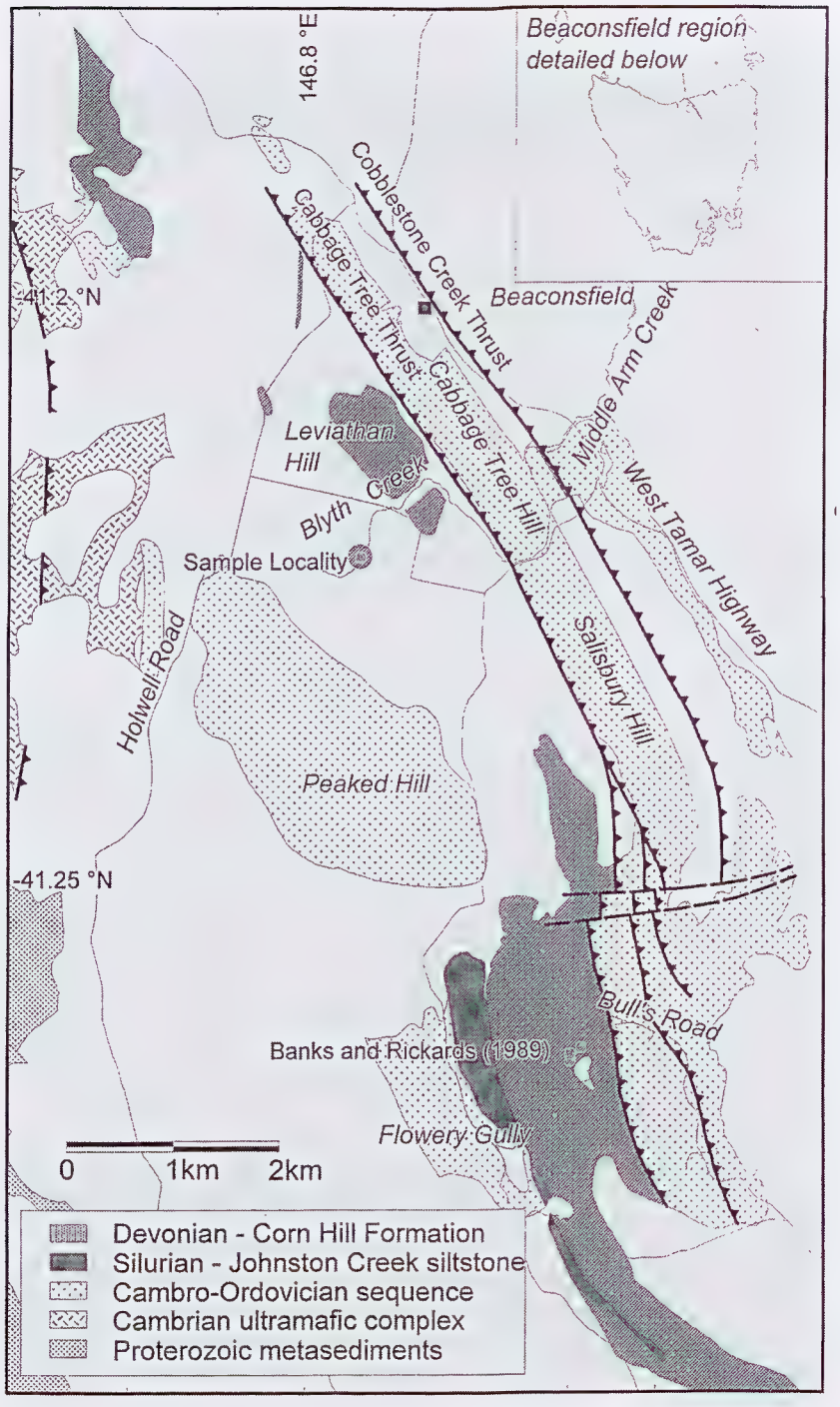

FIG. 1 — Map of the Beaconsfield area, Tasmania, showing the fossil locality, the distribution of the Corn Hill Formation and the postulated positions of relevant thrusts.

southwest-verging imbricate thrusting to explain the repeating strike ridges of Palaeozoic strata in the Beaconsfield district. The discovery of *M. thomasi* described herein has, however, confirmed the recent suggestion. A specimen from Leviathan Hill contains rare, poorly preserved bodies which resemble the stems of vascular plants found in the Panama Group elsewhere in northeastern Tasmania, and one may be dichotomously branched. Partial Bouma sequences have been recently recognised in the Formation on Leviathan Hill (pl. 1B). Although it is clear that the term "Ilfracombe Slate" has priority over "Corn Hill Formation" as a stratigraphic name, strict application of the priority principle would introduce ambiguity and potential confusion. Therefore the later name is preferred (Staines 1985: 91).

Green (1959) mapped a black graphitic shale in poor (and now covered) outcrop, overlying the Flowery Gully Limestone within the township of Beaconsfield, which he named the Grubb Beds and compared with the Mathinna Group of northeastern Tasmania. Recent drilling and underground development at the Beaconsfield Gold Mine has allowed detailed examination of this unit *in situ* and in drill core. Lithologically the rocks are somewhat similar to the Corn Hill Formation, and correlation between the two units has been made (Kennedy 1971, Hills 1998, MacDonald *et al.* 2001). To date, a single cephalopod fragment (UTGD 127752) is the only fossil recovered in Beaconsfield. Similar rocks also crop out along strike 2 km southeast of Beaconsfield and they too were mapped as the Grubb Beds by Green (1959). The reported occurrence of

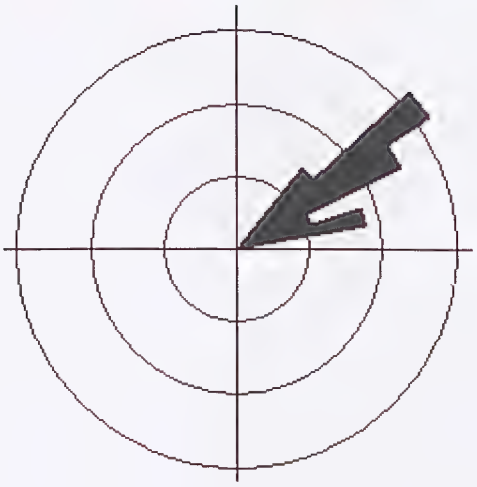

FIG. 2 — Current direction rose, Corn Hill Formation, Bulls Road.

PLATE 1
(A) Flute cast in the Corn Hill Formation, Bulls Road. (B) Bouma units D and E with some C; convolute bedding, pillow structure and flames, Corn Hill Formation, Leviathan Hill; x1.

a high-spired gastropod and a possible biserial graptolite from this location (Öpik in litt. 1962, Banks *et al.* 1989) makes correlation with the Corn Hill Formation improbable, and correlation with the Johnston Creek Siltstone, as suggested by Hills (1982), may be more appropriate. The formation is approximately 50 m thick in the vicinity of the Beaconsfield Gold Mine and is truncated above by the Cobblestone Creek Thrust. The Corn Hill Formation is now considered to be absent at this locality.

SYSTEMATIC PALAEONTOLOGY

Genus *Monograptus* Geinitz, 1852
Monograptus thomasi Jaeger, 1966
Figure 3

1906 *Monograptus dubius* Suess; T.S. Hall, 267, 69–71, ?268, fig. 3.
?1907 *Monograptus* spp.; T.S. Hall, 140–141.
?1907 *Monograptus* cf. *crenulatus* (Tornquist); T.S. Hall, 140–141.
?1907 *Monograptus* sp. (*colonus* group); T.S. Hall, 140–141.
1925 *Monograptus dubius* Suess; Baragwanath, 21, 22.
1933 *Monograptus riccartonensis* Lapworth; Keble, 293, plate.
1935 *Monograptus uncinatus* var. *orbatus* Wood, *M. uncinatus* var. *microspora* (sic) (Jaekel), *M. chimaera* Barrande; Elles (in Lang & Cookson 1935), 422, pl. 32, figs 51–53.
1935 *Monograptus galaensis* Lapworth ex *Monograptus* cf. *galaensis* Lapworth; Thomas (in Lang & Cookson 1935), 422.
1937 *Monograptus uncinatus* var. *orbatus* Wood, *?M. uncinatus* var. *micropoma* (Jaekel); Harris & Thomas, 69, 73–74, pl. 2, figs 23–25, 27–28, ?26, ?30, (non 29).
1960 *Monograptus uncinatus* var. *orbatus* Wood, *M. uncinatus* var. *micropoma* (Jaekel); Thomas, pl. 13, figs 187–188.
1964 *Monograptus* sp. nov. (of the *hercynicus* type) forma A and B; Berry, 9–13, pls 1–2; fig. 1a.
1966 *Monograptus thomasi* sp. nov.; Jaeger, 403–411, pl. 41, figs 3–5; pl. 42, figs 2–7; pl. 43, figs 1 a–c, o.
1970 *Monograptus thomasi* Jaeger; Jaeger, 175–180.
1971a *Monograptus thomasi* Jaeger; Lenz & Jackson, 13–14, pl. 2, figs 1–4, text-figs 3A, B, H, I.
?1971b *Monograptus* cf. *thomasi*; Lenz & Jackson, 131.
1973 *Monograptus thomasi* Jaeger; Jaeger, 104, fig. 1n.
1975 *Monograptus thomasi*, Jaeger; Mu & Ni Yu-nan, 22–24; pl. 7, figs 1–4, 8–11; pl. 8, figs 8 b, 30 d.
1977 *Monograptus thomasi*; Wang Xiao-feng, 196, table 1.
1978 *Monograptus thomasi* Jaeger; Jackson, Lenz & Pedder, pl. 4, fig. 5.
1979 *Monograptus thomasi*; Koren', 99–100, fig. 5:4.
1980 *Monograptus thomasi*; Wang Xiao-feng, chart 2, fig. 2.
1983 *Monograptus thomasi alexandraensis* n. subsp; Jaeger, 252–253, pl.1, fig.13.
1983 *Monograptus thomasi helmckei* n. subsp.; Jaeger, 251–252, pl. 1, figs 6–12, text-figs 5 a–e.
1984 *Monograptus thomasi* Jaeger; Porebska, 117, fig. 7.
1984 *Monograptus thomasi* Jaeger; Garratt & Rickards, fig. 8E.

1985 *Monograptus thomasi* Jaeger; Ni Yu-nan, 7; pl. 3, fig. 6; pl. 4, figs 3, 6, 8.
1987 *Monograptus thomasi* Jaeger; Garratt & Rickards, fig. 2i.
1988 *Monograptus thomasi alexandraensis* Jaeger; Jaeger, 434, fig. 2P.
1988 *Monograptus thomasi thomasi* Jaeger; Jaeger, 434–436, figs 1, 2Q.
1988 *Monograptus thomasi helmckei* Jaeger; Jaeger, 435, fig. 2R.
1989 *Monograptus thomasi* Jaeger; Banks & Rickards 112–116, figs 2, 3, Pl. 1.

Material

About 30 specimens in a deeply weathered pale shale, hemipelagic in origin, with two, poorly developed, foliaceous cleavages (fissilities). There is little noticeable effect of the two cleavages on the dimensions of the diagenetically flattened graptolites — there are no noticeably broad nor noticeably narrow views. Most specimens show little of the thecal details, certainly not through any length of rhabdosome, but in some the typical proximal rhabdosomal curvature is visible, and others have a few proximal or distal thecae preserved. It is almost certain that the two assemblages collected are monotypical and all specimens are referable to *M. thomasi.* Specimen numbers: UTGD 127750 (fig. 3), UTGD 127751 (counterpart).

Details of the locality and stratigraphy are given above.

Diagnosis

Rhabdosomes medium-sized, up to 30 mm long, either straight distally or with slight ventral curvature, and proximally with a characteristic dorsal curvature embracing th 3–10; thecal hoods decrease in size distally where the ventral apertural rim is seen in some cases; the first few thecae have a very slight tendency to metathecal isolation; sicula conspicuously placed dorsally, with pronounced dorsal tongue; dorsoventral width at level of hood of th1 is about 1 mm; more distally is 1.80–1.90 mm; thecal spacing 10–12 over first few mm, 8–10 in 10 mm distally; Σ = 1.20–1.30; thecal overlap about one half; sicula 1.50–1.70 mm, reaching to midway between th1 and th2.

Description

It is possible that the complex deformation of the rock has a cancelling-out effect in terms of spatial deformation on the bedding plane, because the rhabdosomes, reaching 30 mm in length, appear not to be deformed. However, they were diagenetically flattened before deformaton of the rock.

The dorsoventral width reaches 1.90 mm, some being a little more slender distally; the most distal parts of the stipes sometimes show the ventral apertural margin where the hood has receded or been broken off on the counterpart. Thecal overlap shows well only on the specimen illustrated; the interthecal septum curves towards the dorsal side of the rhabdosome about halfway between successive thecal apertures, so that thecal overlap is about half. In one instance, the dorsal thecal foramen, leading to the next theca, is visible (th7, fig. 3).

In the proximal thecae the dorsal thecal hood is always conspicuous and the aperture beneath it, roughly horizontal in disposition, faces proximally. The "hook" occupies about one-third of the rhabdosomal dorsoventral width, perhaps a little more than that on proximal thecae. The sicula is conspicuous and imparts a dorsal deflection to the extreme proximal end. No sicular details are visible save a dorsal hood and short virgella on some specimens. The most distal parts of each colony are either straight or with very gentle ventral curvature.

FIG. 3 — Monograptus thomasi *Jaeger, 1966 (UTGD 127 750), x 5; compression direction indicated; Blyth Creek, Univ. Grid Ref. 55G DQ 483750.5436480; BEACONSFIELD 4843, Geological Atlas 1: 25 000 Series. Tasmanian Geological Survey.*

Remarks

This material is clearly less deformed than that described by Banks & Rickards (1989) from near Flowery Gully about 5 km to the SSE, where stretched and broadened specimens were common. The present material is very close to Jaeger's (1966) types in dimensions, although the latter were deformed, and allowances need to be made. We have provided a full synonymy because this species seems, interestingly, to be quite widely recorded: Tasmania, Victoria, New South Wales, Canada, China and Russia (see synonomy).

Jaeger (1966) and Banks & Rickards (1989) give a detailed comparison with other and related species, which we shall not repeat here. *M. thomasi alexandraensis* Jaeger (1988) differs from the type subspecies in having a more robust proximal end and *M. thomasi helmeckei* has a distinctive and large th1.

CORRELATION

Reed (2001 b) introduced the term "Mathinna Supergroup" to reflect the diverse tectonic history of the Mathinna Group. Within that Supergroup, he defined the Tippogoree

Group as including the Stony Head Sandstone and the Turquoise Bluff Slate of Powell *et al.* (1993), and the Panama Group as including the Bellingham Formation and the Sidling sandstone of Powell *et al.* (1993). The Ordovician to Devonian succession in western Tasmania is rather different and is known as the Wurawina Supergroup, consisting of a Late Cambrian and Early Ordovician Denison Group, a later Ordovician Gordon Group, and two Silurian and Early Devonian Groups, the Eldon and the Tiger Range.

Correlation of the Corn Hill Formation with the Mathinna Supergroup of northeastern Tasmania has already been mentioned. Indeed, the occurrence of Mathinna Supergroup correlates in the Beaconsfield district is not a new concept, early comparisons having been drawn by Green (1959) and Kennedy (1971) without conclusive evidence. However, only recently has an adequate basis for that correlation been suggested by Hills (1982), Baillie *et al.* (1989), Banks & Rickards (1989), MacDonald *et al.*(2001) and Reed (2001a, b). The lithological and sedimentological characters of the Corn Hill Formation are similar to those of the Sidling sandstone of Powell *et al.* (1993) and of the Scamander Formation of Walker (1957), the latter cropping out near the eastern limit of the known Mathinna Supergroup. Baillie (pers. comm.) has recently recognised typical Bouma divisions A, C & D/E of the turbiditic facies in the Corn Hill Formation on Leviathan Hill. This contrasts with the findings of Powell *et al.* (1993:191).

Vascular land plants have been reported from the Corn Hill Formation (Hills 1982, Banks & Rickards 1989), from the Sidling sandstone (Powell *et al.* 1993) and the Scamander Formation (Walker 1957, Rickards & Banks 1979), as well as in several other places in northeastern Tasmania (Cookson 1937) from probably equivalent horizons. The Corn Hill Formation contains pelecypods, an unusual orthoconic cephalopod with tubular walls, an abundance of dacryoconarids and graptolites, as well as other invertebrate fossils. The Scamander Formation contains an orthoconic cephalopod generically, possibly even specifically, the same as that in the Corn Hill Formation, many dacryoconarids, generically and specifically the same as those in the Corn Hill Formation, and a *Monograptus* close in age to but specifically different from that in the Corn Hill Formation (Rickards & Banks 1979).

Depositional and palaeoecological features link the Corn Hill Formation to the Sidling sandstone and more strongly to the Scamander Formation. The Corn Hill Formation and the similar units within the Panama Group further east in Tasmania show close lithological, sedimentological and palaeontological links with the approximately contemporaneous Wilson Creek Shale in the eastern part (Mount Easton Province) of the Melbourne Zone in Victoria, as noted by Banks & Rickards (1989) and earlier authors. The graptolite–land plant association for which the Wilson Creek Shale is "famous" (VandenBerg *et al.* 2000: 151) is also present in the Corn Hill Formation, as noted by Banks & Rickards (1989); there are genera and probably species of bivalves and dacryoconarids in common, and the orthoconic cephalopod with tubular walls was first noted in Australia as *Orthoceras striatopunctatum* by M'Coy (1879) from the Mount Easton Province.

In contrast, the Corn Hill Formation and equivalent units in the Panama Group are somewhat to very different sedimentologically and palaeontologically from the slightly older Bell Shale (Eldon Group) and the approximately contemporaneous Point Hibbs Limestone in western Tasmania. Baillie & Williams (1975: 7) concluded that the Bell Shale was deposited in shallow water, at times from waning currents, and gave no evidence of turbidity currents. Vascular land plants have been reported from the equivalent of the Bell Shale on the Gordon River but are rare to very rare; graptolites have not been reported from Devonian units in the Eldon or Tiger Range Groups. Bivalves have been reported from the Bell Shale but are yet to be properly studied; cephalopods are rare. Dacryoconarids are present but far from abundant. The palaeoecology of the Bell Shale and McLeod Creek Formation, respectively in the Eldon and Tiger Range Groups, and slightly older than the Corn Hill Formation (Talent *et al.* 2000: 254, Correlation Chart), and of the approximately contemporaneous coralline Point Hibbs Limestone (Talent *et al.* 2000: 254), all in westen Tasmania, seems to be quite different from the palaeoecology of the Corn Hill Formation.

IMPLICATIONS

The thrust model used by Gee & Legge (1971, 1979) to explain the structural setting of the Palaeozoic rocks of the Beaconsfield district has stood the test of time (Elliott *et al.* 1993, MacDonald *et al.* 2001, Reed *et al.* 2001) and is not reiterated here. Gee & Legge (1971), in assigning a Cambrian age to the strata on Leviathan Hill, interpreted the Cabbage Tree Thrust as occurring midway between Peaked Hill to the southwest and Cabbage Tree Hill to the northeast. However, recognition of the Corn Hill Formation in the Blyth Creek/Leviathan Hill area has tightly constrained the Cabbage Tree Thrust, at the base of the Cabbage Tree slice of Palaeozoic strata, to a position between Leviathan Hill and Cabbage Tree Hill, as stated by MacDonald *et al.* (2001) (fig. 1). The thrust is one of several in the Beaconsfield district of early Middle Devonian (late-stage Tabberabberan) age, which, as illustrated by Powell & Baillie (1992: 203), facilitated southwest directed crustal shortening. Various models, such as proposed by Powell (1991), Keele *et al.* (1994) and Taheri & Bottrill (1994), suggest that basal thrusts provided a conduit for fluid transport across northeastern Tasmania. As a result of the constraint placed upon the position of the Cabbage Tree Thrust, the latter is now considered to be the primary conduit for the gold-bearing fluids which gave rise to the shear-hosted Tasmania Reef in Cambro-Ordovician sedimentary rocks immediately to the northeast (Hills *et al.* 2001). The Tasmania Reef is the largest gold deposit of its type in Tasmania and it is currently being exploited by the Beaconsfield Gold Mine.

The Corn Hill Formation also has regional stratigraphic and tectonic significance which requires some background explanation. The idea of a terrane boundary of some sort between northeastern and western Tasmania has been argued for a number of years. Leaman *et al.* (1973: 2, 3) suggested that the Tamar Valley separated two structural regimes, and referred to a major lineament along the Tamar line and to the lithological and structural asymmetry across that line up to Middle Palaeozoic times. This idea was taken up and expanded by Williams (1976: 23) who referred to the feature as the "Tamar Fracture System". This Fracture System was seen as separating the Western Tasmania Terrane (Wurawina Supergroup) from the Eastern

Tasmania Terrane (the Mathinna Supergroup). Baillie (1985) referred to it as a "suture" and Williams (1989: 486–491) gave a summary of the elements of the asymmetry. Several of the authors in the Geophysics chapter (13) of Burrett & Martin (1989) referred to the Fracture System, e.g. Leaman (p. 452), Parkinson and Richardson (p. 458), Wellman (pp. 459–461) and Richardson (p.466), and some problems were noted. The existence of the Fracture System (Leaman 1994) and its position, i.e. the boundary between the Eastern and the Western Terrane, have been debated (Elliott *et al.* 1993, Leaman 1994, Hills 1998, Reed 2001b). The present conundrum is the recognition of the Corn Hill Formation, correlated with the Mathinna Supergroup, part of the Eastern Tasmania Terrane, lying not only west of the Tamar River, but also west of outcrops of Wurawina Supergroup rocks, Denison and Gordon Groups, characteristic of the Western Tasmania Terrane.

The germ of one solution to the anomaly of the position of the Corn Hill Formation emerged first in 1973 (before the Formation had been recognised), when a geophysical anomaly in the Dazzler Range west of Beaconsfield was attributed to thrusting (Leaman *et al.* 1973). A little later, Gee & Legge (1979: 29, fig. 9) depicted southwesterly directed thrusting to explain the relationships of Palaeozoic rocks near Beaconsfield. The idea of such thrusting was further developed and applied on a broader scale in northern Tasmania by Powell & Baillie (1992). However, their sections do not explain the occurrence of the Corn Hill Formation (of Eastern Tasmanian Terrane affinity) west of Denison Group rocks (of Western Tasmania Terrane affinity) at Beaconsfield.

A further step in the solution of this anomaly began to emerge when Banks & Smith (1968) suggested the possibility of recumbent folds in the slate at Turquoise Bluff. Subsequently, Gee & Legge (1979: 40) inferred the presence of a recumbent syncline between Beechford and Stony Head. Later, Powell & Baillie (1992) showed that the two formations of the Tippogoree Group were folded into a large recumbent, east-facing syncline. Reed (2001b) suggested that rocks affected by this fold had one more cleavage than the younger Panama Group close by and quoted Cocker (1982), who suggested an age of 423 ± 22 Ma for the low-grade regional metamorphism of the Turquoise Bluff Slate based on Rb/Sr ratios. This suggested to Cocker (1982: 154) a likely age of Middle Silurian, but with an age within the span from Late Ordovician to Early Devonian. He tentatively suggested (Cocker 1982: 155) a correlation with the Benambran Orogeny. This correlation was developed by Reed (2001b). As has been shown earlier, sedimentological and palaeontological characters link the Corn Hill Formation to the Panama Group, more specifically the Sidling sandstone.

Reed (2001b: 792, fig. 6) went further to propose north-easterly directed thrusting in the Benambran Orogeny, followed by deposition of the Panama Group, with later southwesterly directed thrusting in the Devonian as part of the late Tabberabberan movements in order to provide a possible explanation of the current juxtaposition of the Mathinna and Wurawina Supergroups near Beaconsfield. The boundary between the two supergroups may have been in about the same place from Early Ordovician to Early Devonian time or may have varied in position. In neither case has any original boundary been recognised. Any boundary or boundaries may well be hidden below cover rocks in the Tamar Valley region or thrust out in the Benambran and/or Tabberabberan Orogenies, as suggested in principle by Powell *et al.* (1998, fig. 15), who showed the Western and Eastern Terranes separated by a gap of about 70 km in the Emsian.

The recognition of Benambran deformation in the Mathinna Supergroup is a key difference between the models of Reed (2001b) and Powell & Baillie (1992). As some earlier authors, Powell & Baillie (1992) correlated the Mathinna Supergroup with the Melbourne Zone in Victoria, a zone in which Benambran deformation is not observed. Reed (2001b) maintained that the deformation of the Tippogoree Group associated with the Benambran Orogeny demonstrated tectonic affiliation of northeastern Tasmania with the Tabberabbera Zone, immediately east of the Melbourne Zone in Victoria, presumably in Late Ordovician and Early Silurian time.

Powell & Baillie (1992: 207) noted the similarity in the type of cleavage developed between the Stony Head Sandstone and rocks on the south coast of NSW, the Adaminaby Group, several areas of Lower Ordovician rocks in the Benambra Terrane and a cleavage approaching stripy cleavage in the "Lower Ordovician part of the the Melbourne zone" (i.e. in the western part of that zone). Thus, Moore *et al.* (1998: 108, fig. 1) showed an Adaminaby Group equivalent in the Tabberabbera Zone (Pinnak Sandstone, with which Reed (2001b) correlated the Stony Head Sandstone) and in the Bendigo Zone (Castlemaine Supergroup) extending for a time into the Melbourne Zone. The Bendigo Zone, like the Tabberabbera Zone, exhibits Benambran deformation. Therefore correlation of the Stony Head Sandstone with the Castlemaine Group is not inconsistent with the observations made by Powell & Baillie (1992) and accommodates the key element of Benambran deformation recognised by Reed (2001b).

The graptolite *Loganograptus* cf. *logani* from the Early Ordovician Turquoise Bluff Slate (Banks & Smith 1968) suggests a relationship with the Bendigo Zone or the western part of the Melbourne Zone of Victoria as a distinct possibility. Elsewhere in the Mathinna Supergroup, late Ludlow graptolites occur at Golden Ridge northwest of Scamander (Rickards *et al.* 1993); these suggest affinity with the Humevale Formation in the Darraweit Guim Province in the north-central part of the Melbourne Zone. In even younger (Pragian) parts of the Mathinna Supergroup, the Scamander Formation and the Corn Hill Formation, faunal and sedimentological relationships are with the Wilson Creek Shale in the Mount Easton Province of the Melbourne Zone. *Monograptus thomasi* (Banks & Rickards 1989 and herein) has been recorded from the Wilson Creek Shale but not from units in the Tabberabbera Zone; although this may be the result of ecological differences, the benthonic faunal elements as well as the planktonic graptolites are similarly restricted.

Thus, sedimentological, faunal and structural characters of the Mathinna Supergroup are consistent with affinity of these northeastern Tasmania rocks with rocks in the Bendigo Zone in pre-Benambran time and show a strong affinity with those in the Melbourne Zone after that Orogeny.

Reed (2001b) also recognised a parallel between the lack of evidence of Benambran deformation in the Late Cambrian and Ordovician Denison and Gordon Groups, i.e. pre-Benambran rocks, in western Tasmania generally and particularly in those rocks in the Beaconsfield area (overlain disconformably by the Corn Hill Formation), and a similar lack in the correlative rocks in the Melbourne

Zone in Victoria. He suggested that the Wurawina Supergroup was shielded from the effects of the Benambran deformation by underlying continental basement, in much the same way that Cayley *et al.* (1999) rationalised the lack of Benambran deformation of pre-Benambran Palaeozoic rocks in the Melbourne Zone as being due to shielding by underlying continental basement. VandenBerg *et al.* (2000: 357, 358, fig. 5.2) showed the basement beneath central Victoria as the Selwyn Block, which they argue represents a continuation of the Proterozoic to Cambrian crust beneath Tasmania deformed in the Cambrian Tyennan Orogeny. This correlation is strongly supported by the continuity of aeromagnetic data across Bass Strait (VandenBerg *et al.* 2000: 358, fig. 5.2).

Remnants of the Selwyn Block have been mapped in isolated locations in southern Victoria, notably Waratah Bay. Indeed, Cayley *et al.* (2002: 233) mapped the upper contact of the Selwyn Block, the Tyennan Unconformity, at Waratah Bay, and correlate the strata above the unconformity directly with the Wurawina Supergroup in Tasmania. VandenBerg *et al.* (2000:159) and Cayley *et al.* (2002: 228, 234, fig. 2) considered that the Selwyn Block at Waratah Bay and extending to the north beneath the Melbourne Zone was a topographic high, the Waratah Bay Platform, for much of the Early and Middle Palaeozoic. The Wurawina Supergroup correlates of the Waratah Bay Platform at Waratah Bay are thin, and the sequence is incomplete in comparison to those in Tasmania. The Waratah Fault transposes the Devonian Liptrap Formation, which VandenBerg *et al.* (2000: 148, fig 2.106) correlated with the Eildon Sandstone of the Mount Easton Province of the Melbourne Zone, immediately underlying the Wilson Creek Shale. This relationship between Wurawina Supergroup correlates and the Melbourne Zone at Waratah Bay in Victoria, has strong parallels with that between the Wurawina Supergroup and the Corn Hill Formation at Beaconsfield in Tasmania and warrants further study.

SUMMARY AND CONCLUSIONS

Recent discovery of a Pragian (Early Devonian) graptolite (*Monograptus thomasi*) west of Beaconsfield has allowed recognition of a northerly extension of the previously known outcrop of the Corn Hill Formation and requires that the Cabbage Tree Fault lies east of its earlier postulated position, thus closer to Beaconsfield. This fault is thought to have been a feeder channel to the gold deposit at Beaconsfield.

The sedimentological characters and fauna of the Corn Hill Formation strongly suggest connection with the Scamander Formation of the Panama Group of the Mathinna Supergroup in northeastern Tasmania and with rocks in the Melbourne Zone in Victoria. This affinity seems to be consistent with older but post-Benambran connections. Pre-Benambran connections of the Supergroup seem most likely to have been with the Bendigo Zone.

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APPENDIX

Corn Hill Formation — Definition and Comments by P.B. Hills

The Corn Hill Formation is defined as that succession of cleaved micaceous shaley siltstone with lesser quartzwacke sandstone, siltstone and shale units, of generally turbiditic character cropping out east of Flowery Gully and extending northwest over a strike length of approximately 12 km to the vicinity of Leonardsburg in the Beaconsfield district in northern Tasmania (fig. 1). The type locality of the formation is at 146°50'E, 41°16'S on Bulls Road, where it was first mapped in substantial road cuttings as the Corn Hill beds by Hills (1982) and where Banks & Rickards (1989) reported the first occurrence in Tasmania of *Monograptus thomasi.*

The Corn Hill Formation exhibits alternation from shale to quartzwacke sandstone over intervals of approximately a metre, many forming Bouma sequences. Sedimentary structures such as slumping, flute casting (e.g. pl. 1A), cross bedding, and small scale erosional cut-offs are common (specimens in the collection of the School of Earth Sciences, University of Tasmania, include numbers 61 846–50 and 63 909–17). Readings on flute casting and cross bedding, in particular, indicate current movement from the WSW (fig. 2). Fossils occurring at the type locality include, in addition to *M. thomasi,* pelecypods, e.g. *Actinopteria meridionalis, Praecardium* sp. and several others not yet identified, the dacryoconarid *Styliolina minuta,* numerous cephalopods, a trilobite and plant fragments (specimens in the collection of the School of Earth Sciences, University of Tasmania, include numbers 121 286–305 and 123 5834–628 and others). Many of the invertebrate fossils are fragmentary and show signs of transport prior to burial. The recently discovered occurrence of *M. thomasi* in Blyth Creek, 5 km to the NNW of the type locality, is the only other known fossil locality in the formation. The Corn Hill Formation is considered to have been deposited in a moderate energy, deep water, outer shelf environment.

The stratigraphic and structural setting of the Corn Hill Formation was recently revised by MacDonald *et al.* (2001). The unit disconformably overlies the Johnston Creek Siltstone of Late Ordovician or Early Silurian age. The latter unit may be a correlate of the Arndell Sandstone (including the Westfield Beds) at the top of the Gordon Group of southern-central Tasmania or of the Eldon Group of western Tasmania and represents the uppermost strata of the Wurawina Supergroup in the Beaconsfield district. The Corn Hill Formation may be up to 600 m thick, although the actual thickness is difficult to determine, due to poor outcrop in a region of some structural complexity. There is evidence of folding, perhaps of recumbent folding, within the unit at Flowery Gully. Specifically, the Corn Hill Formation is apparently confined to the Peaked Hill slice of Palaeozoic strata, as defined by Gee & Legge (1979), is truncated by the Cabbage Tree Thrust, and is not mapped in the overlying Cabbage Tree slice or the Cobblestone Creek slice.

The Corn Hill Formation is correlated with the Sidling sandstone, the upper formation of the Mathinna Supergroup of northeastern Tasmania, and with the Scamander Slate and Quartzite, on lithological, sedimentological and palaeontological grounds. Thus, it is considered, as part of the Mathinna Supergoup, to be a unit within the Lachlan Fold Belt. It is also correlated palaeontologically with the Wilson Creek Shale in the Melbourne Zone of the Lachlan Fold Belt in Victoria.

The Corn Hill Formation was first recognised as a Pragian correlative of the Mathinna Supergroup by Hills (1982). Previously, Kennedy (1971) had noted similarity between the rocks east of Flowery Gully and the Mathinna Supergroup, without further detail. He recalled an earlier suggestion by Green (1959) that rocks then exposed in Beaconsfield (the Grubb Beds) were also similar to rocks in the Mathinna Supergroup, but the Grubb Beds have subsequently been correlated with the Johnston Creek Siltstone and the Eldon Group of western Tasmania. The Mathinna Supergroup correlation was recognised by Elliott *et al.* (1993), a correlation discounted by Powell *et al.* (1993), but the sedimentological correlation has now been accepted after further examination in the field by Baillie (pers. comm.). The unit was further discussed by MacDonald *et al.* (2001) and Reed (2001b).

FOLIAGE INSECT DIVERSITY IN DRY EUCALYPT FORESTS IN EASTERN TASMANIA

by H.J. Elliott, R. Bashford, S.J. Jarman and M.G. Neyland

(with four tables, one text-figure and two appendices)

ELLIOTT, H.J., BASHFORD, R., JARMAN, S.J. & NEYLAND, M.G., 2002 (31:xii): Foliage insect diversity in dry eucalypt forests in eastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 136: 17–34. ISSN 0080–4703. Forestry Tasmania, 79 Melville St., Hobart, Tasmania 7000, Australia.

Species numbers and composition of the insect fauna occurring on trees and shrubs were studied in dry eucalypt forests in eastern Tasmania over nine years. In all, 1164 named and putative species representing 17 orders and 157 families were collected. The bulk of the species belonged to the orders Coleoptera (28%), Hymenoptera (25%), Hemiptera (18%), Lepidoptera (14%) and Diptera (10%). Of the species collected, 388 — about one-third — were identified at least to genus or species level. These included 21 named species not previously listed in the Tasmanian insect fauna and 90 undescribed species.

A list of 22 host plants for 171 insect species was compiled from records of 132 insect species observed feeding during the study and from previous records of insect/host plant associations for 39 insect species found on the study plots. Most insects were feeding on eucalypts (127 insect species) and acacias (38 species). The most widely distributed and commonly collected species were several well-known pests of eucalypts: *Gonipterus scutellatus* (Coleoptera: Curculionidae), *Uraba lugens* (Lepidoptera: Noctuidae), *Amorbus obscuricornis* (Hemiptera: Coreidae), *Chaetophyes compacta* (Hemiptera: Machaerotidae) and *Eriococcus coriaceous* (Hemiptera: Eriococcidae). Host plants supporting the richest insect fauna were *Eucalyptus amygdalina* (74 species), *E. obliqua* (64), *E. viminalis* (46), *Acacia dealbata* (35), *E. dalrympleana* (33), *E. sieberi* (31), *E. delegatensis* (30), *E. pulchella* (24) and *E. globulus* (19).

The broad-striped ghost moth, *Fraus latistria* Walker (Lepidoptera: Hepialidae), was collected during the study. This species is classified as 'rare' on the list of Tasmania's threatened fauna and the collection established a new locality record.

Key Words: Insect diversity, host plants, eucalypt forests, Tasmania.

INTRODUCTION

Prior to the late 1960s, dry eucalypt forests in eastern Tasmania were selectively logged for sawlogs and small volumes of fence posts and firewood. Following the development of an export woodchip industry, large areas of these forests were harvested and regenerated by clearfelling all merchantable timber, burning the logging slash to prepare a seedbed and aerially sowing with eucalypt seed (Felton & Cunningham 1971).

The effects of forest operations associated with the woodchip industry on flora, fauna and other natural values became the subject of considerable public concern in the 1970s (Senate Standing Committee on Science and the Environment 1977) and research projects were initiated by various agencies to provide quantitative data to assist rational debate on the issue.

The invertebrates are an obvious target group for such studies because of their extraordinary species richness across a wide range of habitats and their key role in essential ecological functions including soil conditioning, nutrient cycling, pollination and biological control. There have been many investigations of individual forest insect species, particularly commercially important pests, in dry eucalypt forests, but surprisingly few studies of the species composition of the general insect fauna.

Knowledge of the insect fauna of Tasmanian eucalypt forests has been limited by the paucity of collections in some forest types and taxonomic deficiencies for many insect groups. There is a scarcity of ecological data for most of the insect fauna in these forests apart from commercially important pests (Elliott & de Little 1984, Elliott *et al.* 1998) and some individual species or groups. Long-term studies of the size and composition of the forest insect fauna at specific Tasmanian sites are rare although some intensive short-term studies (1–2 years) in rainforest and wet eucalypt forests have provided valuable data on species composition. Coy *et al.* (1993) collected 618 species of insects from 20 orders in cool temperate rainforest, and Hickman & Hill (1978) collected 105 named insect species and many more unidentified species from 17 orders, mainly from moss and leaf litter, in the Lower Gordon Scientific Study in southwestern Tasmania. Several studies of particular insect groups have been conducted in dry eucalypt forests in Tasmania. For example, in northeastern Tasmania, McQuillan *et al.* (1998) reported on the seasonality of 126 species of geometrid moths in eucalypt forests, including a dry forest site, and Bashford (1993) recorded 81 species of macrolepidoptera from dry eucalypt forests over a five-year period.

In 1978 we established a series of plots in several dry eucalypt forests scheduled for harvesting in eastern Tasmania as part of a study of the effects of clearfelling and burning on vegetation and its associated insect fauna over the long term (i.e., at least 20 years). This paper records the species diversity and host plant records of the insect fauna found on tree and shrub vegetation during the first nine years of the study. Other aspects of the study, including the effects of harvesting and regeneration on the flora and insect fauna, are being documented elsewhere.

METHODS

Plot Establishment

Three plots were established in each of five proposed logging coupes containing mature, unlogged, dry eucalypt forest in eastern Tasmania. The location and basic descriptors of these forests are summarised in table 1 and figure 1. Plot size was 75 m x 50 m (0.375 ha), with the corners marked by wooden pegs and wire stakes. Within each coupe, the three plots were located to sample a range of dominant eucalypt associations usually strongly related to aspect.

Following harvesting and regeneration treatments, plots were re-established in the same locations by replacing the wooden stakes and wire pegs with permanent steel star pickets as corner markers. Due to rescheduling of harvesting operations, all plots in SW 51 and one plot in TO 54 were not harvested.

Vegetation

Mature, unlogged, dry forests in the study areas had an overstorey of eucalypt associations comprising two or more of the following species: *Eucalyptus amygdalina* Labill., *E. obliqua* L' Hèrit., *E. delegatensis* R. Baker, *E. pulchella* Desf., *E. globulus* Labill., *E. ovata* Labill., *E. sieberi* L. Johnson, *E. tenuiramis* Miq. and *E. viminalis* Labill. (table 1). These were relatively open forests with the stocking of mature eucalypt stems ranging from 109 to 339 stems per hectare (Elliott *et al.* 1991).

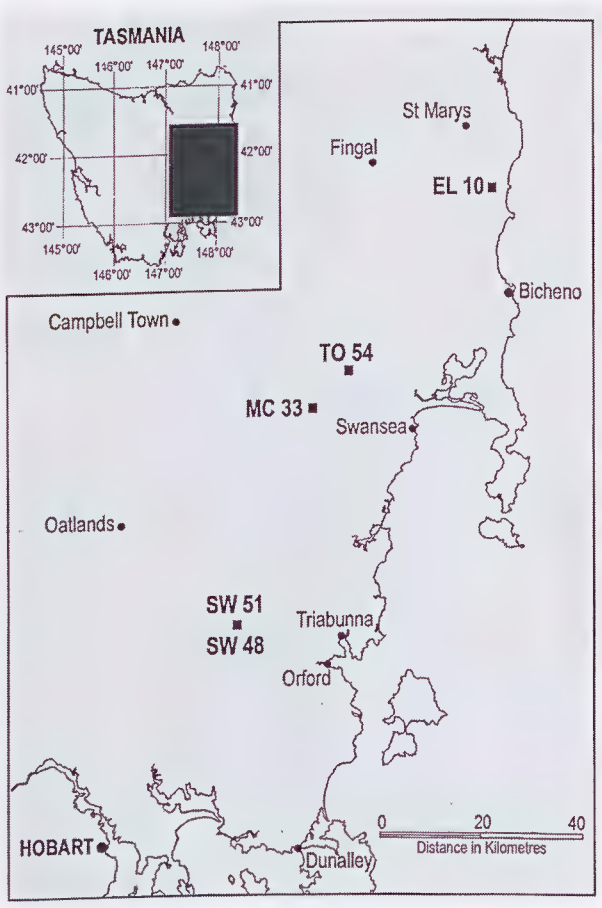

FIG. 1 — Coupe locations.

TABLE 1
Site descriptors for harvesting units (coupes) sampled for insect fauna

Coupe	Location (1:100 000) Tasmap ref.)	Altitude a.s.l. (m)	Mean annual rainfall (mm)	Parent material	Dominant eucalypt species
SW 48	Nugent EN 543 940	320	585	Triassic sandstone	*E.obliqua* *E.amygdalina* *E.viminalis*
SW 51	Nugent EN 510 965	380	585	Triassic sandstone	*E.obliqua* *E.amygdalina* *E.viminalis*
MC 33	LittleSwanport EP 668 392	580	900	Jurassic dolerite	*E.delegatensis* *E.amygdalina*
TO 54	LittleSwanport EP 762 473	460	849	Jurassic dolerite	*E.obliqua* *E.tenuiramis*
EL 10	Break O'Day FP 030 837	300	686	Jurassic dolerite	*E.sieberi* *E.obliqua*

*Nearest meteorological station to coupe

TABLE 2
Plant species sampled for insects on each harvesting unit

Plant species	Coupe				
	SW 48	SW 51	TO 54	MC 33	EL 10
Acacia dealbata* Link	*	*	*	*	*
Acacia genistifolia Link			*		
Acacia mearnsii De Wild.			*		
Acacia melanoxylon R.Br.			*	*	
Acacia myrtifolia (Smith)Willd.					*
Acacia terminalisn(Salisb.)Macbr.			*		*
Acacia verniciflua A.Cunn.					*
Acacia verticillata (L'HÈrit.)Willd.			*	*	*
Allocasuarina littoralis (Salisb.)L.Johnson			*		
Amperea xiphoclada (Sieb. ex Sprengel) Druce			*		
Aotus ericoides (Vent.) G.Don	*	*	*		*
Banksia marginata Cav.	*	*	*	*	
Bossiaea cinerea R.Br.		*			
Bursaria spinosa Cav.		*	*	*	*
Cassinia aculeata (Labill.)R.Br.	*	*		*	
Comesperma volubile Labill.			*		
Cyathodes glauca Labill.	*	*		*	*
Daviesia ulicifolia Andrews			*	*	*
Dianella tasmanica Hook.f.			*	*	
Epacris impressa Labill.		*	*	*	
Eucalyptus amygdalina Labill.	*	*	*	*	*
Eucalyptus dalrympleana Maiden		*	*		
Eucalyptus delegatensis R.Baker	*		*	*	*
Eucalyptus globulus Labill.	*		*		*
Eucalyptus obliqua L'HÈrit.	*	*	*	*	*
Eucalyptus ovata Labill.					*
Eucalyptus pulchella Desf.			*		
Eucalyptus sieberi L.Johnson					*
Eucalyptus tenuiramis Miq.	*	*	*		
Eucalyptus viminalis Labill.	*	*	*	*	*
Exocarpos cupressiformis Labill.	*	*	*	*	*
Gahnia grandis (Labill.)S.T.Blake		*	*	*	
Goodenia ovata Smith				*	*
Lepidosperma elatius Labill.			*	*	*
Leptospermum scoparium Forst. & Forst.f.	*	*	*	*	*
Leucopogon ericoides (Smith) R.Br.		*			
Lomandra longifolia Labill.		*	*		
Lomatia tinctoria (Labill.) R.Br.	*	*	*	*	*
Monotoca glauca (Labill.) Druce					*
Olearia lirata (Sims.) Hutch.		*		*	*
Olearia viscosa (Labill.) Benth.				*	*
Oxylobium ellipticum (Labill.) R.Br.	*				
Polystichum proliferum (R.Br.) C.Presl				*	
Pomaderris apetala Labill.				*	*
Pteridium esculentum (Forst.f.) Cockayne	*	*	*	*	*
Pultenaea daphnoides J.Wendl.	*				*
Pultenaea gunnii Benth.	*		*	*	*
Pultenaea juniperina Labill.	*	*	*	*	*
Senecio minimus Poiret	*	*	*	*	*
Tetratheca labillardierei J.Thompson		*			

* Bold type indicates plant species which were confirmed hosts for insects collected in the study.

The understorey was characterised by short (up to 4 m), often prickly shrubs with a significant grassy/sedgy component in some areas. Seventy-two species of dicotyledons, 24 monocotyledons and five fern species were recorded across all the study areas before logging commenced. The most common plant families and genera present were Fabaceae (*Pultenaea*), Mimosaceae (*Acacia*), Proteaceae (*Banksia, Lomatia*), Asteraceae (*Olearia, Senecio*), Epacridaceae (*Epacris*), Xanthorrhoeaceae (*Lomandra*) and Poaceae (*Poa, Danthonia*). A detailed analysis of the botany from the study areas is in preparation.

Logging and regeneration burning removed most of the overstorey and severely damaged many of the understorey plants. The young forests established following logging have very high stockings of eucalypts (1000–5000 stems ha^{-1}) compared with the forests present before logging (Elliott *et al.* 1991). The species composition of the post-logging vegetation at all the study sites is similar to that which existed prior to logging although there has been an overall increase in species richness, and the structure and relative dominance of the various species has changed (M. Neyland, unpublished data).

Insect Sampling

Insect sampling was conducted on all plots at one-month intervals prior to the logging and regeneration treatment and at approximately three-month intervals (mid-spring, summer, autumn and winter) following treatment. The number of sampling occasions over the nine years ranged from 41–45 for plots within the coupes EL 10, MC 33 and TO 54. However, because of coupe rescheduling and other operational reasons, plots within coupes SW 48 and SW 51 were sampled only 16 and 26 times respectively. Insects occurring on vegetation greater than 30 cm in height were sampled using sweeping, beating and hand-collecting techniques. On each sampling occasion, three to five individuals of each plant species on each plot were swept with a standard 30 cm-diameter collecting net and the captured insects were stored in 70% ethyl alcohol or pinned for later identification. Insects were also sampled by holding a 1 m^2 canvas beating tray beneath the foliage of the plant and collecting (by hand or with an aspirator) all insects dislodged by beating branches with five blows from a stick. Where sufficient plants of each species were available, beating was conducted on different individual plants to those sampled by sweeping; otherwise, the same plants were sampled by both methods. Prior to logging in the mature forests, only the lower foliage of mature trees and small trees beneath the canopy could be sampled, whereas in the newly regenerated forests all sections of the tree canopy could be accessed. The plant species sampled are listed in table 2. On each sampling occasion, all insect species collected from each plant species were recorded and insect/host plant associations noted where feeding was observed.

Light trapping was conducted on suitable nights at all plots throughout the sampling period. Initially, the light traps used were constructed from galvanised sheet metal and consisted of a rectangular killing box supporting a 15-watt UV fluorescent tube covered with a perspex roof. In the second year following logging, these traps were replaced by cylindrical plastic light traps supporting a vertically mounted, 15-watt fluorescent UV tube surrounded by three perspex vanes. Light traps were charged with dichlorvos in the form of Shell Pest Strips®.

Insect Identification

Insects were initially identified to family level and sent to taxonomic specialists for further identification. For families where taxonomic assistance was unavailable, lists of coded putative species were assembled by the authors. An extensive reference collection of named and coded insect species was maintained to assist with identifications throughout the study.

Data Set

Information collected from sampling the plots consisted of occurrences of insect species on plant species for each plot and sampling date, noting any feeding activity. No abundance data were collected. Data for the 522 sampling occasions were stored in DECODA (Minchin 1991), a data-handling package which allows basic statistics on species numbers and composition of the fauna to be calculated easily. It also presents the data in a format suitable for the input files used by several other programs which undertake multivariate analyses.

Nomenclature

Species nomenclature follows Naumann (1993) for insects and Buchanan (1999) for plants.

RESULTS

Composition of the Insect Fauna

In all, 1164 species (named and putative) representing 17 orders and 157 families were collected from plants and in light traps on the plots during the study. The level to which these species could be identified varied greatly depending on taxonomic problems in the groups and the availability of taxonomic expertise. One-third (388) of these species were identified at least to genus level. The total insect fauna collected during the study is listed by order and family in appendix 1.

The bulk of the insect fauna was contained in the orders Coleoptera (322 species), Hymenoptera (294 species), Hemiptera (209 species), Lepidoptera (169 species) and Diptera (112 species) (table 3). Over half the species of Coleoptera collected were leaf-eating beetles (Chrysomelidae) and stem-boring and leaf-feeding weevils (Curculionidae). The most species-rich families among the sap-feeders (Hemiptera) were the Psyllidae (79 species) and the Cicadellidae (40 species). Most of the Hymenoptera collected were parasitoids and gall formers in the superfamily Chalcidoidea (120 species) and the families Braconidae (50 species) and Ichneumonidae (28 species). Twenty-nine species of ants (Formicidae) were recorded during the study. Larvae of Lepidoptera were common defoliators of a wide range of host plants, although most species recorded were adult moths caught in light traps (table 4). Geometridae

TABLE 3
Summary of insect fauna by taxonomic group

Order	Number of families	Number of named species	Number of putative species	Total number of species	Percentage of total insect fauna
Coleoptera	29	86	236	322	28
Hymenoptera	22	31	263	294	25
Hemiptera	25	113	96	209	18
Lepidoptera	25	128	41	169	14
Diptera	31	-	112	112	10
Orthoptera	2	6	4	10	<1
Collembola	8	6	3	9	<1
Thysanoptera	1	-	9	9	<1
Psocoptera	4	6	1	7	<1
Blattodea	1	1	5	6	<1
Neuroptera	3	5		5	<1
Plecoptera	2	2	4	6	<1
Odonata	2	1	1	2	<1
Trichoptera	1	-	1	1	<1
Mecoptera	1	1	-	1	<1
Mantodea	1	1	-	1	<1
Dermaptera	1	-	1	1	<1
TOTAL	159	387	777	1164	

TABLE 4
Number of species in families of Lepidoptera recorded from light trap collections

Family	Number of species
Anthelidae	7
Arctiidae	8
Cossidae	1
Cosmopterygidae	1
Gelechiidae	1
Geometridae	59
Gracillariidae	2
Heliozelidae	2
Hepialidae	7
Lasiocampidae	5
Limacodidae	1
Lycaenidae	2
Lymantriidae	2
Noctuidae	24
Notodontidae	3
Nymphalidae	7
Oecophoridae	8
Pieridae	1
Psychidae	3
Pyralidae	4
Saturniidae	1
Sphingidae	1
Thaumetopoeidae	2
Tortricidae	5
Zygaenidae	1
TOTAL	158

(66 species) and Noctuidae (24 species) were the dominant families of Lepidoptera.

The 388 species named to at least genus level by specialist taxonomists included 21 named species which are not included in the list of Tasmanian insect fauna (Semmens *et al.* 1992) and a further 90 species yet to be formally described (see appendix 1). Over half of these 'new' species (63) were psyllids (Hemiptera: Psyllidae) with the remainder scattered among the other orders. Many more insects in the collection of 776 unidentified putative species are expected to be previously unrecorded in Tasmania.

The broad-striped ghost moth, *Fraus latistria* Walker (Lepidoptera: Hepialidae), one of the named species collected, is listed in *Tasmania's Threatened Fauna Manual* (Bryant & Jackson 1999) and has a status of 'rare' as defined by Tasmania's *Threatened Species Protection Act* 1995. This species was collected by light-trap sampling on 21 March 1978 in coupe SW 51, a new locality record for the species.

The composition of the insect fauna showed only minor variation across the study area. A variety of multivariate analyses were undertaken on the data beginning with detrended correspondence analysis using the program DECORANA (Hill 1979a). Because of limitations on the size of data sets with microcomputers, the more robust procedure for indirect gradient analysis, multidimensional scaling (see Minchin 1991), was used only on subsets of the data. It was performed with the program MDS (Minchin 1991), using global non-metric multidimensional scaling followed by hybrid non-metric multidimensional scaling as recommended by Kantvilas & Minchin (1989). The classificatory program TWINSPAN (Hill 1979b) was also used to examine the data. None of the analyses showed any separation of insect assemblages according to coupe of origin. The data do not appear to be well-suited to the techniques because of the low number of species in many samples and the high number of species recorded only a few times (over three-quarters of the species were collected on less than five sampling occasions). Many analyses were re-run with rare species and sample outliers were removed progressively but little improvement was achieved.

Species Richness

The numbers of species collected from each of the harvesting coupes were generally similar taking into account differences in altitude, rainfall, geology and vegetation. Species numbers collected per coupe over the sampling period ranged from 464 to 556 species, with the exception of SW 48 where the numbers were much lower (286 species).

Differences in species richness were more marked at the plot level. The total number of species per plot ranged from 180 to 308 except for SW 48. Again the total number of species was lower than in the other coupes, ranging from 118 to 140 species over the three plots. The lower figures for SW 48 at both the coupe and plot level are attributed, at least in part, to the smaller number of sampling occasions possible due to operational constraints. In all coupes and in all plots species numbers varied greatly on individual sampling occasions. Typical figures ranged from 5–20 species, the highest number on any single sampling occasion being 42 and the lowest being zero.

As expected, species richness varied markedly according to the season of collection when seasons were arbitrarily defined as follows: September to November (spring), December to February (summer), March to May (autumn) and June to August (winter). Analysis of the total collection on this basis showed that the numbers per collection (mean ± s.e.) for spring, summer, autumn and winter were 12.9 ± 0.7 (n = 131), 13.7 ± 0.7 (n = 157), 10.5 ± 0.6 (n = 129) and 5.5 ± 0.4 (n = 101) respectively. Seasonal occurrences of many of the main plant-feeding insects, particularly defoliators, were common to most plots. For example, in early spring, young eucalypt leaves were often eaten by the adults of small melolonthine scarab beetles, mainly *Heteronyx* spp. Several species of Lepidoptera larvae were collected during winter and spring and larvae of the fireblight beetle, *Acacicola orphana*, were common on *Acacia dealbata* and *A. mearnsii* in the same period where these tree species were present on the plots. In late spring, summer and autumn, leaf beetle (Chrysomelidae) eggs, larvae and adults were present on several species of eucalypts together with their common predators: adult soldier beetles (*Chauliognathus* spp.) and larval and adult ladybird beetles (Coccinellidae).

Insect/Host Plant Associations

A total of 132 insects named to genus or species level were recorded actually feeding on 22 of the 50 plant species sampled on the plots during the survey. An additional 39 insect species had known hosts (Bashford 1990) on the plots where they were collected but were not observed actually feeding at the time of collection. Most of these insects were recorded feeding on eucalypts (127 insect species) and acacias (38 species) with lower numbers recorded from *Banksia* (5 species), *Allocasuarina* (4), *Exocarpos* (4), *Leptospermum* (3), *Goodenia* (2) and *Pultenaea* (1). Twenty-five insect families contained eucalypt feeders, with most species recorded from Chrysomelidae (leaf beetles) and Psyllidae (lerps). Four of the six eucalypt-feeding sawflies (Pergidae) found in Tasmania (Elliott & Bashford 1996) were collected on the plots (appendix 1).

A listing of these 171 species by their host plants is shown in appendix 2. Eighty-five of these species were found feeding on only one host plant species during the study but host specificity is not well documented and cannot be assumed. The most polyphagous and commonly collected species were several well-known pests of eucalypts and acacias: eucalypt weevil *Gonipterus scutellatus* (Gyllenhal) (ten eucalypt hosts); gumleaf skeletonizer *Uraba lugens* Walker (nine eucalypt hosts); gumtree bug *Amorbus obscuricornis* (Westwood) and the chrysomelid beetle *Paropsis porosa* Erichson (each with eight eucalypt hosts); gumtree scale *Eriococcus coriaceous* Maskell, the machaerotid *Chaetophyes compacta* (Walker), the chrysomelid beetles *Trachymela rugosa* (Chapuis) and *Chrysophtharta nobilitata* (Erichson), and the psyllid *Glycaspis* sp. (each with seven eucalypt hosts).

Host plants in rank order supporting the richest insect fauna were *Eucalyptus amygdalina* (74 species), *E. obliqua* (64), *E. viminalis* (46), *Acacia dealbata* (35), *E. dalrympleana* (33), *E. sieberi* (31), *E. delegatensis* (30), *E. pulchella* (24) and *E. globulus* (19).

DISCUSSION

The 1164 insect species collected during this study, together with the host plant records for 171 insect species, represent a significant increase in our knowledge of the insect fauna in Tasmania's dry eucalypt forests. Among the 388 species identified at least to genus level, the collection of 21 named species not previously listed in the Tasmanian insect fauna (Semmens *et al.* 1992) and a further 90 yet to be described but apparently new species emphasise the low level of knowledge about the insect fauna in these forests. The high proportion of Psyllidae in this previously unlisted collection is in part due to the availability of specialist taxonomic expertise for that particular group. Further taxonomic investigation of other groups will undoubtedly result in many more previously unlisted species. The total number of species (identified and putative) collected in the study represents nearly 8% of the estimated 15 000 non-marine insect species in Tasmania (Greenslade 1985).

Although a large number of species was collected during the study reported here, total species numbers and composition of collections were obviously influenced by the extent and frequency of sampling at the study sites, climatic conditions at the time of sampling, stages of plant development present (e.g. flowering, new shoot extension) and many other factors. For much of the study, sampling of each plot occurred at quarterly intervals and was conducted regardless of weather conditions. Therefore, some collections may be biased towards species which are relatively sedentary feeders on their host plants and so less affected by rain, wind and cool conditions.

Levels of endemism for the insects collected are not known although Greenslade (1985) reported that the highest endemicity in the Tasmanian insect fauna occurred in the rainforest and alpine environments, and dry forests probably had low to medium levels, perhaps in the range 20–70%, varying widely between insect groups. For example, endemicity of 30% was reported for Coccinellidae (one of the most species-rich groups collected in our study) in eucalypt forests (Greenslade 1985).

The collection of the broad-striped ghost moth, *Fraus latistria*, at the unlogged SW 51 coupe in eastern Tasmania extends the distribution of this rare insect. This species has been previously recorded only from the Hobart and Launceston areas and Scotts Peak Dam in southwestern Tasmania (Bryant & Jackson 1999).

Although no similar studies have been previously reported from these forests in Tasmania, other studies in different forest types or in different habitats in dry eucalypt forests on mainland Australia are available for comparison of the size and composition of elements of the insect fauna. In a study by Neumann (1978) using systematic malaise trap sampling of mature dry peppermint-gum eucalypt forest (*E. dives–E. radiata–E. macrorhyncha*) in Victoria, the most abundant (in terms of number of specimens collected) were (in rank order): Diptera, Hymenoptera, Coleoptera, Hemiptera and Lepidoptera. These orders were also the most species-rich orders of insects recorded in our Tasmanian study although Diptera ranked lowest rather than highest as in the Victorian study.

In a study of beetle communities using periodic malaise trapping in the same forests in Victoria, Neumann (1979) recorded 199 species of Coleoptera (beetles) from 47 families. The most frequently collected families in this study were Chrysomelidae, Staphylinidae, Alleculidae, Coccinellidae, Scarabaeidae, Mordellidae, Curculionidae, Melyridae and Anisotomidae. In two studies of the species composition of the litter-inhabiting Coleoptera in Victorian dry eucalypt forests (*E. obliqua–E.radiata–E. rubida*), 109 species from 30 families (Neumann *et al.* 1995) and 105 species from 31 families (Collett & Neumann 1995) were collected. Undescribed species comprised 67% and 72% respectively of the collections from these studies. In our Tasmanian study, 322 named and putative species of Coleoptera from 29 families were collected on vegetation and the proportion of undescribed species (74%) was similar to that recorded for the Victorian fauna.

Ohmart *et al.* (1983) in a study of leaf-chewing insects in subalpine *E. delegatensis–E. dives–E. pauciflora* forest in the Australian Capital Territory (ACT), reported that the major taxa (expressed as numbers of insects per kilogram of foliage dry weight) were micro-Lepidoptera, Geometridae, Chrysomelidae and Curculionidae; Cercopidae, Cicadellidae and Fulgoroidea were the major families of sap feeders. Similarly, in the Tasmanian study, Chrysomelidae and Curculionidae were the most species-rich families of Coleoptera, and Geometridae was the most species-rich family of Lepidoptera even though the eucalypt forest types sampled were quite different from the subalpine forests of the ACT. Leafhoppers (Cicadellidae) and psyllids (Psyllidae) were the predominant families of sap-feeders collected in eastern Tasmania, but psyllids were rarely collected in the subalpine forests (Ohmart *et al.* 1983). Although there are some obvious similarities between the foliage-dwelling insect fauna of Tasmanian dry eucalypt forests and some mainland forests, definitive comparisons are difficult because of the different measures used (species richness, number of specimens, insects per weight of foliage) and habitats sampled.

As stated above, Geometridae was the most species-rich family of Lepidoptera recorded in this study. The larvae of many species are common defoliators in these dry forests, particularly of eucalypts and acacias. Nine of the geometrid species collected were also recorded by McQuillan *et al.* (1998) in dry eucalypt forest at Old Chum Dam in north-eastern Tasmania.

In a recent invertebrate survey of rainforest in Tasmania, 618 insect species from 22 orders were collected by sweeping and beating vegetation (the sampling technique used in the present study) and the most frequently collected families were Collembola and Diptera, with Coleoptera, Hymenoptera, Psocoptera and Lepidoptera reasonably abundant. Again, undescribed species made up some 75% of the total. Overall, using several sampling methods across many rainforest habitats, Coleoptera was the most diverse group containing 367 species from 44 families (Coy *et al.* 1993), a similar result to that obtained from our sampling of Tasmanian dry eucalypt forests.

The large number of insects feeding on eucalypts and acacias in the list of insect/host plant associations is not unexpected considering the domination of eucalypts, and to a lesser extent acacias, in these forests. In particular, the high number of eucalypt stems per hectare in the young regenerating forests (Elliott *et al.* 1991) in which the post-logging sampling was conducted, their fast growth rate and larger tree size compared to other plants would contribute to the high capture rate among eucalypt feeders compared to the general fauna. In addition to the dominance of eucalypts and acacias at the study sites, many of the insects feeding on these host genera are widely distributed and

polyphagous. They were therefore frequently collected on all plots, together with their predators and parasites. These are important contributing factors to the lack of separation of insect assemblages according to coupe of origin.

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APPENDIX 1
Total insect fauna collected from study plots

Order/Family/Species

Blattodea
- Blattidae
  - *Platyzosteria melanaria* (Erichson)
  - 5 unidentified species

Coleoptera
- Alleculidae
  - 2 unidentified species
- Anobiidae
  - 5 unidentified species
- Bostrychidae
  - *Xylion collaris* (Erichson)
- Buprestidae
  - *Cisseis acudata* (Kirby)
  - *Castiarina wilsoni* (Saunders)
  - *Ethon affine* (Laporte & Glory)
  - *Germarica lilliputana* (Thomson)
  - *Melobasis innocua* (Thomson)
  - *Melobasis sparsa* (Levy)
  - *Nascioides parryi* (Hope)
- Byrrhidae
  - 1 unidentified species
- Cantharidae
  - *Chauliognathus lugubris* (Fabricius)
  - *Chauliognathus nobilitatus* (Erichson)
  - 14 unidentified species
- Carabidae
  - 5 unidentified species
- Cerambycidae
  - *Ancita marginicollis* (Boisduval)
  - *Bethelium signiferum* (Newman)
  - *Coptocercus rubripes* (Boisduval)
  - *Pytheus erosus* (Macleay)
  - *Tessaromma sericans* (Erichson)
  - *Tessaromma undatum* Newman
  - *Toxeutes arcuatus* (Fabricius)
  - *Zoedia divisa* (Pascoe)
  - 2 unidentified species
- Chrysomelidae
  - *Acacicola hamadryas* Stal
  - *Acacicola orphana* (Erichson)
  - *Altica pagana* Blackburn
  - *Cadmus australis* Boisduval
  - *Cadmus crincicollis* Boisduval*
  - *Cadmus* sp.4#
  - *Cadmus strigillatus* Chapuis
  - *Chrysophtharta aurea* Blackburn
  - *Chrysophtharta bimaculata* (Olivier)
  - *Chrysophtharta crucata* (Boisduval)*
  - *Chrysophtharta decolorata* (Chapuis)
  - *Chrysophtharta nobilitata* (Erichson)
  - *Chrysophtharta philomela* Blackburn
  - *Chrysophtharta* sp.a#
  - *Chrysophtharta* sp.b#
  - *Chrysophtharta* sp.c#
  - *Chrysophtharta* sp.f#
  - *Chrysophtharta* sp.h#
  - *Paropsides umbrosa* Chapuis
  - *Paropsis aegrota* var. *elliotti* Selman*
  - *Paropsis deboeri* Selman
  - *Paropsis dilatata* Erichson
  - *Paropsis porosa* Erichson
  - *Paropsis* sp.a#
  - *Paropsis tasmanica* Baly
  - *Paropsisterna nucea* (Erichson)
  - *Platycolaspis australis* Jacoby
  - *Trachymela papulosa* (Chapuis)*
  - *Trachymela rugosa* (Chapuis)
  - 58 unidentified species
- Cleridae
  - *Blackburniella hilaris* (Westwood)
  - *Eleale* sp.
  - 4 unidentified species
- Coccinellidae
  - *Cleobora mellyi* Mulsant
  - *Coccinella repanda* Thunberg*
  - 21 unidentified species
- Colyiidae
  - 3 unidentified species
- Cucujoidea
  - 4 unidentified species
- Curculionidae
  - *Acalonoma pusilla* Blackburn*
  - *Autetobius* sp.#
  - *Belus bidentatus* (Donovan)
  - *Belus bimaculatus* Pascoe
  - *Euthyphasis acuta* Pascoe*
  - *Gonipterus gibberus* Boisduval
  - *Gonipterus lepidotus* Gyllenhal
  - *Gonipterus scutellatus* (Gyllenhal)
  - *Gonipterus* sp.
  - *Haplonyx* sp.
  - *Merimnetes* sp
  - *Pachyura australis* Hope
  - *Myllorhinus multidentatus* (Chevrolet)
  - *Myllorhinus bicaudatus* (Boisduval)
  - *Rhadinosomus lacordairei* Pascoe
  - *Scotasmus* sp.
  - *Syarbis alcyone* Lea
  - 65 unidentified species
- Elateridae
  - *Agrypnus pictipennis* (Candeze)
  - 11 unidentified species
- Lathridiidae
  - 2 unidentified species
- Lucanidae
  - *Syndesus cornutus* Fabricius
- Lycidae
  - *Metriorrhynchus* sp.a
  - *Metriorrhynchus* sp.b
- Melandryidae
  - 4 unidentified species
- Melyridae
  - 5 unidentified species
- Mordellidae
  - 5 unidentified species
- Nitidulidae
  - 7 unidentified species
- Oedemeridae
  - *Dohrnia miranda* Newman
  - 1 unidentified species
- Phalacridae
  - 1 unidentified species
- Ptinidae
  - 1 unidentified species
- Scarabaeidae
  - *Diphucephala colaspidoides* (Gyllenhal)
  - *Heteronyx crinitus* Blackburn
  - *Heteronyx* sp.a
  - *Heteronyx* sp.b
  - *Heteronyx* sp.c
  - *Liparetus atratus* Burmeister
  - *Liparetus convexus* Boisduval
  - *Phyllotocus erythropterus* Blanchard
  - *Xylonychus piliger* Blanchard
  - 4 unidentified species
- Scraptiidae
  - *Scraptia* sp.
  - 1 unidentified species

APPENDIX 1 cont.

Staphylinidae
8 unidentified species
Tenebrionidae
Lepispilus sulcicollis (Boisduval)
2 unidentified species

Collembola
Hypogastruridae
Hypogastrura purpurescens (Lubbock)
Entomobryidae
Australotomurus sp.#
Lepidocyrtoides sp.#
Sminthuridae
Rastriopes sp#.
Polykatianna sp.#
Tomoceridae
Lepidophorella sp.#
Paronellidae
3 unidentified species

Dermaptera
Forficulidae
1 unidentified species

Diptera
Agromyzidae
2 unidentified species
Anisopodidae
1 unidentifed species
Asilidae
6 unidentifed species
Bibionidae
3 unidentifed species
Bombyliidae
1 unidentified species
Calliphoridae
3 unidentifed species
Cecidomyiidae
3 unidentified species
Ceratopogonidae
3 unidentifed species
Chironomidae
14 unidentified species
Chloropidae
7 unidentified species
Clusiidae
1 unidentified species
Culicidae
1 unidentified species
Dolichopodidae
6 unidentified species
Empididae
8 unidentified species
Fergusoninidae
1 unidentified species
Heliomyzidae
2 unidentified species
Lauxaniidae
3 unidentified species
Muscidae
1 unidentified species
Mycetophilidae
5 unidentified species
Perissommatidae
1 unidentified species
Phoridae
4 unidentified species
Platystomatidae
2 unidentified species
Rhagionidae
3 unidentified species
Scatopsidae
1 unidentified species
Scenopinidae
1 unidentified species
Sciaridae
8 unidentified species
Stratiomyidae
3 unidentified species
Syrphidae
4 unidentified species
Tabanidae
3 unidentified species
Tachinidae
5 unidentified species
Tipulidae
6 unidentifed species

Hemiptera
Acanthosomatidae
Anischys sp.
Alydidae
1 unidentified species
Aphididae
4 unidentified species
Cicadellidae
Alocephalus ianthe (Kirkaldy)*
Austrolopa brunensis Evans
Batracomorphus augustatus (Evans)*
Batracomorphus elegans (Evans)
Batracomorphus ?elegans
Batracomorphus sp.#
Euleimonios sp.nov.#
Haplodelphax iuncicola (Kirkaldy)*
Ipoella sp.#
Kahaono sp.
Neotartessus flavipes (Spanberg)
Paralimnus smithtoniensis Evans
Rosapaella evansi Webb
Rosopaella cuprea (Walker)
Rosopaella sp.
Rubria sp.
Rubria sp a.
Rubria sp b.
Stenocotis depressa (Walker)
Tenuitartessus blundellensis (Evans)
Trocnada sp.#
Vulturnus sp.#
Zygina evansi (Ross)
Zygina zealandica (Myers)
15 unidentified species
Cicadidae
Cicadetta torrida (Erichson)
Cixiidae
4 unidentified species
Coccidae
7 unidentified species
Coreidae
Amorbus obscuricornis (Westwood)
Gelonus tasmanicus (Le Guillou)
Eniocephalidae
1 unidentified species
Eriococcidae
Eriococcus coriaceus Maskell
Eurymelidae
Eurymeloides bicincta (Erichson)
3 unidentified species
Flatidae
Siphanta hebes (Walker)
Lygaeidae
Euander lacertosus (Erichson)
8 unidentified species

APPENDIX 1 cont.

Machaerotidae
- *Chaetophyes compacta* (Walker)
- 3 unidentified species

Membracidae
- *Naunus tasmaniae* (Fairmaire) *
- 4 unidentified species

Miridae
- 19 unidentified species

Nabidae
- *Nabis* sp.

Pentatomidae
- *Cermatulus nasalis* (Westwood)
- *Dictyotus caenosus* (Westwood)
- 16 unidentified species

Piesmidae
- 1 unidentified species

Pseudococcidae
- 5 unidentified species

Psyllidae
- *Aacanthocnema* sp.#
- *Aacanthocnema? dobsoni* (Fr.)*
- *Acizzia* ?sp.#
- *Acizzia* sp.#
- *Acizzia* sp.a#
- *Acizzia* sp.b#
- *Acizzia* sp.c#
- *Acizzia* sp.d#
- *Acizzia* sp.e#
- *Acizzia* sp.f#
- *Acizzia* sp.g#
- *Acizzia* sp.h#
- *Acizzia* sp.i#
- *Acizzia* sp.j#
- *Acizzia* sp.k#
- *Acizzia* sp.l#
- *Anoeconeossa copidiformis* Taylor
- *Australopsylla* ?(nr.)sp.a#
- *Australopsylla ?marmorata*
- *Australopsylla marmorata* (Froggatt)
- *Australopsylla* sp.a#
- *Australopsylla* sp.b#
- *Australopsylla* sp.c#
- *Australopsylla* sp.d#
- *Cardiaspina ?* sp.#
- *Cardiaspina ?spinifera* (Froggatt)
- *Creiis ?* sp.#
- *Creiis* sp. "tas"#
- *Creiis* sp.a#
- *Ctenarytaina* b1#
- *Ctenarytaina* I#
- *Ctenarytaina* k#
- *Ctenarytaina* sp.#
- *Ctenarytana* a3#
- *Ctenarytana* b#
- *Ctenarytana* c#
- *Ctenarytana* d#
- *Ctenarytana* d2#
- *Ctenarytana eucalypti* (Maskell)
- *Glycaspis dobsoni* Moore*
- *Glycaspis dreptodria* Moore
- *Glycaspis planitecta* Moore
- *Glycaspis* sp.#
- *Hyalinaspis ?rubra*
- *Hyalinaspis rubra* (Froggatt)
- *Hyalinaspis* sp.#
- *Phellopsylla* a#
- *Phellopsylla* b#
- *Phellopsylla* c#
- *Phellopsylla* d#
- *Phellopsylla* e#
- *Phellopsylla* n#
- *Phellopsylla* n2#
- *Phellopsylla* sp.#
- *Platylobria maddeni* Taylor
- Schedotrioza ?#
- *Schedotrioza* a#
- *Schedotrioza* b#
- *Schedotrioza* c#
- *Schedotrioza* d#
- *Schedotrioza* sp.#
- *Schedotrioza* sp.1#
- *Schedotrioza* sp.2#
- *Spondyliaspis?* gen. et sp. nov.#
- *Trioza ?* sp#
- *Trioza ?*b#
- *Trioza ?*c#
- *Trioza* a#
- *Trioza* b#
- *Trioza* d#
- *Trioza* e#
- *Trioza nr.*a#
- *Trioza nr.*b#

Reduviidae
- 5 unidentified species

Scutelleridae
- *Scutiphora pedicellata* (Kirby)

Thaumastocoridae
- *Baclozygum depressum* Bergroth

Tingidae
- *Epimixia* sp.

Hymenoptera

Apidae
- *Apis mellifera* Linnaeus

Bethylidae
- 8 unidentified species

Braconidae
- *Doryctes* sp.#
- *Syngaster* sp.#
- *Trichiohelcon rufoniger* (Turner)
- 47 unidentified species

Chalcidoidea
- 120 unidentified species

Chrysididae
- 3 unidentified species

Cleptidae
- 3 unidentified species

Colletidae
- 5 unidentified species

Cynipidae
- 6 unidentifed species

Eumenidae
- 2 unidentified species

Formicidae
- *Anonychomyrma* sp.a#
- *Anonychomyrma* sp.b#
- *Anonychomyrma* sp.c#
- *Anonychomyrma* sp.d#
- *Anonychomyrma* sp.e#
- *Anonychomyrma* sp.f#
- *Anonychomyrma* sp.g#
- *Anonychomyrma* sp.h#
- *Camponotus* sp.a
- *Camponotus* sp.b
- *Camponotus* sp.c
- *Camponotus* sp.d
- *Meranoplus* sp.
- *Myrmecia* sp.a
- *Myrmecorhynchus* sp.a
- *Myrmecorhynchus* sp.b
- *Notoncus* sp.
- *Prolasius* sp.a

APPENDIX 1 cont.

Prolasius sp.b
Rhytidoponera sp.a
Stigmacros sp.a
Stigmacros sp.b#
7 unidentified species
Ichneumonidae
28 unidentified species
Megalyridae
1 unidentified species
Megastigmidae
13 unidentified species
Mutillidae
Ephutomorpha dorsigera (Westwood)
Pergidae
Lophyrotoma interrupta (Klug)
Perga affinis insularis Riek
Pergagrapta bella (Newman)
Pseudoperga lewisii (Westwood)
Platygasteridae
2 unidentified species
Pompilidae
2 unidentified species
Proctotrupidae
6 unidentified species
Scoliidae
1 unidentified species
Sphecidae
1 unidentified species
Tenthredinidae
1 unidentified species
Tiphiidae
7 unidentified species

Lepidoptera
Anthelidae
Anthela acuta (Walker)
Anthela nicothoe (Boisduval)
Anthela ocellata (Walker)
Anthela sp.a
Anthela sp.b
Pterolocera amplicornis Walker
Pterolocera sp.a
Arctiidae
Castulo doubledayi (Newman)
Nyctemera amica (White)
Palaeosia bicosta (Walker)
Phaeophlebosia furcifera Walker
Scoliacma bicolora Boisduval
Spilosoma glatignyi (Le Guillou)
Utetheisa pulchelloides Hampson
Cossidae
Culama australis Walker
Cosmopterigidae
Macrobathra sp.
Gelechiidae
Protolechia sp.
Geometridae
Boarmia lyciaria (Guenee)
Boarmia sp a
Boarmia sp.b
Capusa senilis Walker
Chlenias sp.
Chlorocoma dichloraria (Guenee)
Chlorodes boisduvalaria (Le Guillou)
Chrysolarentia vicissata (Guenee)
Cleora bitaeniaria (Le Guillou)
"*Cidaria*" *subochraria* Doubleday*
Crypsiphona ocultaria (Donovan)
Dichromodes ainaria Guenee
Ectropis excursaria (Guenee)
Ectropis exsuperata (Walker)
Eucyclodes buprestaria Guenee
Euloxia meandraria (Guenee)
Gastrinodes bitaeniaria (Le Guillou)
Heliomystis electrica Meyrick
Hypobapta eugramma (Low.)*
Hypobapta percomptaria (Guenee)
Melanodes anthracitaria Guenee
Microdes squamulata Guenee
Mnesampela comarcha Meyrick
Mnesamplela privata (Guenee)
Monoctenia falernaria Guenee
Niceteria macrocosma (Low.)*
Paralaea beggaria Guenee
Plesanemma fucata (Felder & Rogenhofer)
Stathmorrhopa berberi (Turner)
Thalaina inscripta Walker
Thalaina selenaea Doubleday
36 unidentified species
Gracillariidae
Acrocercops laciniella (Meyrick)
1 unidentified species
Heliozelidae
Heliozela sp.
1 unidentified species
Hepialidae
Abantiades latipennis Tindale
Abantiades sp.a
Aenetus ligniveren (Lewin)
Fraus latistria Nielsen & Kristensen
Oncopera intricata Walker
Oxycanus sordidus Herrich-Schaffer
Trictena argentata Herrich-Schaffer
Hypertrophidae
Hypertropha tortriciformis (Guenee)
Lasiocampidae
Digglesia australasiae (Fabricius)
Digglesia sp.a
Entometa fervens (Walker)
Opsirhina albigutta (Walker)
Pernattia exposita (Lewin)
1 unidentified species
Limacodidae
Doratifera pinguis (Walker)
Lycaenidae
Neolucia hobartensis (Miskin)
Paralucia aurifer (Blanchard)
Lymantriidae
Acyphas leucomelas (Walker)
Teia anartoides Walker
Noctuidae
Agrotis infusa (Boisduval)
Agrotis porphyricollis Guenee
Amphipyra sanguinipuncta Guenee
Dasygaster nephelistis Hampson
Dasygaster padockina (Le Guillou)*
Diarsia intermixta (Guenee)
Euplexia sp.
Eutrichopidia latinus (Donovan)
Helicoverpa punctigera (Wallengren)
Heliothis rubrescens (Walker)
Neumichtis sepultrix (Guenee)
Nola aulacota Meyrick
Pantydia sparsa Guenee
Persectania ewingii (Westwood)
Praxis edwardsii Guenee
Praxis sp.
Rhapsa suscitalis (Walker)
Rictonis atra (Guenee)
*Rictonis gypsina**
Rictonis sp. nr.*flexirena* (Walker)
Rictonis sp.

APPENDIX 1 cont.

Sideridis costalis (Walker)*
Uraba lugens Walker
Notodontidae
Danima banksiae (Lewin)
Hylaeora inclyta (Walker)
Sorama bicolor Walker
Nymphalidae
Argynnina hobartia (Westwood)
Geitoneura klugi (Guerin-Meneville)
Heteronympha merope (Fabricius)
Heteronympha penelope Waterhouse
Junonia villida (Fabricius)
Vanessa kershawi (McCoy)
Oreixenica lathoniella (Westwood)
Oecophoridae
Agriophara sp.
Artiastis sp.
Cryptophasa albacosta Lewin
Garrha callianassa (Meyrick)
Machimia parthenopa (Meyrick)
Oenochroa sp.
Stathmopoda cephalaea Meyrick
Wingia lambertella (Wing)
Pieridae
Pieris rapae (Linnaeus)
Psychidae
Clania sp.
Lepidoscia arctiella Walker
Narycia sp.
Pyralidae
Gauna aegusalis (Walker)
Hednota sp.
Macalla sp.
Uresiphita ornithopteralis (Guenee)
Saturniidae
Opodiphthera helena (White)
Sphingidae
Hippotion scrofa (Boisduval)
Thaumetopoeidae
Epicoma melanospila (Wallengren)
Trichiocercus mesomelas (Walker)*
Tortricidae
Acropolitis ptychosema Turner
Epiphyas ashworthana (Newman)
Epiphyas plastica (Meyrick)
Epiphyas postvittana (Walker)
Epiphyas sp.
Palaeotoma styphelana Meyrick
2 unidentified species
Zygaenidae
Pollanisus viridipulverulentus Guerin-Meneville

Mantodea
Mantidae
Orthodera ministralis (Fabricius)

Mecoptera
Bittacidae
Harpobittacus australis Klug

Neuroptera
Chrysopidae
Chrysopa edwardsi Banks
Hemerobiidae
Drepanacra binocula (Newman)
Mantispidae
Calomantispa venusta Lambkin
Campion australasiae (Guerin)
Campion callosus Lambkin

Odonata
Corduliidae
1 unidentified species
Gomphidae
Austrogomphus guerini (Rambur)

Orthoptera
Acrididae
Austroicetes sp.
Gastrimargus musicus (Fabricius)
Phaulacridium vittatum (Sjostedt)
Russalpia albertisi (Bolivar)
Tasmaniacris tasmaniensis (Bolivar)
3 unidentified species
Tettigoniidae
Acripeza reticulata Guerin
1 unidentified species

Plecoptera
Gripopterygidae
3 unidentified species
Notonemouridae
Kimminosperla sp.
Spaniocerca sp.
1 unidentified species

Psocoptera
Caeciliidae
Caecilius semifuscatus (Tillyard)
Caecilius sp.
Ectopsocidae
Ectopsocus briggsi McLachlan
Peripsocidae
Peripsocus sp.
Philotarsidae
Haplophallus paraguttatus (Tillyard)*
Haplophallus sp.
1 unidentified species

Thysanoptera
Phlaeothripidae
9 unidentified species

Trichoptera
Hydropsychidae
1 unidentified species

* Indicates species not listed in the Tasmanian insect fauna as listed by Semmens *et al.* 1992.
# Indicates undescribed 'new' species.

APPENDIX 2
Insect/host plant associations*

		Acacia dealbata	*Acacia melanoxylon*	*Acacia myrtifolia*	*Acacia terminalis*	*Acacia verticillata*	*Allocasuarina littoralis*	*Banksia marginata*	*Eucalyptus amygdalina*	*Eucalyptus dalrympleana*	*Eucalyptus delegatensis*	*Eucalyptus globulus*	*Eucalyptus obliqua*	*Eucalyptus ovata*	*Eucalyptus pulchella*	*Eucalyptus sieberi*	*Eucalyptus tenuiramis*	*Eucalyptus viminalis*	*Exocarpos cupressiformis*	*Goodenia ovata*	*Leptospermum scoparium*	*Pultenaea gunnii*	*Pultenaea juniperina*
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Acrididae	*Phaulacridium vittatum*										+		+*										
Anthelidae	*Anthela* sp. a	+																					
	Anthela sp. b																	+					
	Pterolocera sp.	+*																					
Bostrychidae	*Xylion collaris*							+*					+*					+*					
Cerambycidae	*Ancita marginicollis*	+																					
	Bethelium signiferum	+*																					
	Coptocercus rubripes								+*				+*			+*		+*					
	Epithora dorsalis								+*				+*			+*		+*					
	Pytheus erosus												+*										
	Toxeutes sp.												+*	+*									
	Zoedia divisa	+*																					
Chrysomelidae	*Acacicola hamadryas*	+																					
	Acacicola orphana	+				+																	
	Acacicola sp. b																					+	+
	Cadmus australis								+			+*	+*		+*								
	Cadmus crinicollis															+		+					
	Cadmus strigillatus														+*								
	Cadmus sp. 4								+	+					+	+		+					
	Cadmus sp. a								+														
	Chrysophtharta aurea								+							+*		+					
	Chrysophtharta bimaculata										+	+*	+*										
	Chrysophtharta crucata														+								
	Chrysophtharta decolorata								+						+		+*						
	Chrysophtharta nobilitata								+	+			+		+	+	+	+					
	Chrysophtharta philomela										+												
	Chrysophtharta variicollis								+		+		+	+	+			+					
	Chrysophtharta sp. a								+														

APPENDIX 2 cont.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Chrysophtharta sp. c												+		+								
	Chrysophtharta sp. h								+														
	Haltica pagana	+																					
	Nascio parryi											+*											
	Paropsides umbrosa	+																					
	Paropsis aegrota elliottii								+		+		+			+							
	Paropsis deboeri								+				+				+	+					
	Paropsis dilatata								+				+*				+*						
	Paropsis porosa								+	+		+	+	+*		+	+	+					
	Paropsis tasmanica											+*	+					+					
	Paropsis sp. a																	+					
	Paropsisterna nucea									+			+*					+					
	Trachymela papulosa								+*		+*		+	+*									
	Trachymela rugosa								+	+	+*		+*		+	+		+					
Cicadidae	*Cicadetta torrida*	+										+*				+							
Cicadellidae	*Tenuitartessus blundellensis*								+*						+*								
Coreidae	*Amorbus obscuricornis*								+	+	+		+		+	+	+	+					
	Gelonus tasmanicus								+		+		+			+		+					
Curculionidae	*Acalonoma pusilla*																			+*			
	Belus bidentatus	+*																					
	Belus bimaculatus	+*																					
	Gonipterus gibberus															+		+					
	Gonipterus lepidotus								+														
	Gonipterus scutellatus								+	+	+	+	+	+	+	+	+	+					
	Merimnetes sp.								+	+								+					
	Rachiodes bicaudatus											+*						+					
	Rachiodes multidentatus								+		+	+											
	Rhadinosomus lacordairei									+													
	Syarbis alcyone												+			+							
Eriococcidae	*Eriococcus coriaceous*								+		+	+	+		+	+		+					
Eurymelidae	*Eurymeloides bicincta*								+*														
Gelechiidae	*Protolechia* sp.									+	+				+								
Geometridae	*Boarmia* sp.	+*																					
	Capusa senilis								+*									+*					
	Chlenias sp.	+							+		+									+			
	Chlorocoma dichloraria	+*																					
	Chlorodes boisduvalia																				+		
	Cleora bitaeniaria								+														
	Crypsiphona occultaria								+				+*										

APPENDIX 2 cont.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Dichromodes ainaria	+*																					
	Ectropis excursaria																		+*				
	Euloxia meandraria								+*														
	Hypobapta percomptaria								+														
	Microdes squamulata	+*																					
	Mnesampela comarcha									+*			+*					+*					
	Mnesampela privata									+	+	+					+						
	Monoctenia falernaria												+*										
	Stathmorrhopa berberi								+*														
	Thalaina inscripta	+*																					
	Thalaina selenaea		+*																				
Gracillariidae	*Acrocercops* sp.								+	+	+		+			+		+					
Heliozelidae	*Heliozela prodela*												+										
Hepialidae	*Aenetus ligniveren*												+*										
Lasiocampidae	*Pernattia exposita*						+																
Limacodidae	*Doratifera pinguis*								+*		+					+		+*					
Lymantriidae	*Acyphas leucomelas*	+	+						+		+								+*				
	Teia anartoides	+*							+*				+*						+				
Lyonetiidae	*Stegommata sufuratella*							+															
Machaerotidae	*Chaetophyes compacta*								+	+	+		+			+	+	+					
Membracidae	*Daunus tasmaniae*	+*																					
Noctuidae	*Leucania eugrapha*								+*														
	Uraba lugens								+	+	+	+	+		+	+	+	+					
Notodontidae	*Danima banksiae*							+*															
	Hylaeora inclyta									+*													
	Sorama bicolor												+*										
	Trichocerus mesomelas								+*				+*										
Oecophoridae	*Garrha callianassa*							+															
	Hypertropha tortriciformis										+		+					+					
	Machimia parthenopa								+*			+*											
	Oenochroa sp.								+														
Pergidae	*Lophyrotoma interrupta*															+							
	Perga affinis insularis											+*	+										
	Pergagrapta bella								+														
	Pseudoperga lewisii								+									+					
Psychidae	*Clania* sp.								+														
	Lepidoscia arctiella	+							+														
	Narycia sp.												+			+							
Psyllidae	*Acizzia acaciaedealbata*	+																					

APPENDIX 2 cont.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Acizzia sp. a	+																					
	Acizzia sp. b	+																					
	Acizzia sp. c	+																					
	Acizzia sp. d	+																					
	Acizzia sp. e	+				+																	
	Acizzia sp. g	+																					
	Acizzia sp. i			+																			
	Acizzia sp. j				+																		
	Acizzia sp. k	+																					
	Acizzia sp. L			+																			
	Anoeconeossa copidiformis								+		+		+			+		+					
	Anoeconeossa sp.								+		+		+		+	+		+					
	Australopsylla marmorata								+							+							
	Australopsylla sp. B																	+					
	Australopsylla sp. c									+													
	Australopsylla sp. d								+														
	Cardiaspina spinifera																	+					
	Cardiaspina sp. nov.								+														
	Cardiaspina sp. nov. a								+				+										
	Creiis 'Tas' sp.								+	+			+			+		+					
	Ctenarytaina eucalypti									+		+	+										
	Ctenarytaina sp.								+	+			+					+					
	Ctenarytaina sp. b								+				+		+	+							
	Ctenarytaina sp. c									+													
	Ctenarytaina sp. d											+											
	Glycaspis dobsoni										+												
	Glycaspis dreptodria									+			+		+								
	Glycaspis planitecta												+										
	Glycaspis sp.								+	+	+		+		+	+		+					
	Hyalinaspis rubra								+	+	+							+					
	Hyalinaspis sp.								+				+		+			+					
	Hyalinaspis sp. a											+											
	Phellopsylla sp.										+												
	Phellopsylla sp. a												+		+								
	Phellopsylla sp. b	+						+	+	+			+		+								
	Phellopsylla sp. c								+							+							
	Phellopsylla sp. e									+													
	Phellopsylla sp. g								+														
	Schedotrioza sp.								+				+										

APPENDIX 2 cont.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
	Schedotrioza sp. a								+														
	Schedotrioza sp. b									+													
	Schedotrioza sp. c									+			+										
	Schedotrioza sp. i								+									+					
	Trioza sp. b						+																
	Trioza sp. c						+																
	Trioza sp. d						+												+				
Pyralidae	*Gauna aegusalis*	+*																					
	Macalla sp.																				+		
Saturniidae	*Opodiphthera helena*								+	+			+*					+*					
Scarabaeidae	*Diphucephala colaspidoides*	+*																					
	Heteronyx crinitus								+		+												
	Heteronyx sp. a								+	+	+		+					+					
	Heteronyx sp. b																	+					
	Heteronyx sp. c								+				+			+							
	Liparetus atratus												+					+					
	Liparetus convexus									+*			+		+								
	Phyllotocus erythropterus																				+		
	Xylonychus pilifer								+*							+							
Stenomatidae	*Agriophara* sp.												+										
Thaumetopoeidae	*Epicoma melanospila*								+				+*		+*			+*					
Tingidae	*Epimixia* sp.	+							+	+			+										
Tortricidae	*Acropolitis ptychosema*								+*		+*		+										
	Epiphyas ashworthana	+*										+*											
	Epiphyas postvittana												+*										
	Palaeotoma styphelana								+*			+	+*					+					
TOTALS		35	2	2	1	2	4	5	74	33	30	19	64	5	24	31	10	46	4	2	3	1	1

* Species with known hosts as indicated but not actually feeding when collected.

TASMANIAN ABORIGINES AND DNA

by John C. Presser, Albert J. Deverell*, Alan J. Redd and Mark Stoneking

(with one table)

Presser, J. C., Deverell, A. J., Redd, A. J. & Stoneking, M., 2002 (31:xii): Tasmanian Aborigines and DNA. *Papers and Proceedings of the Royal Society of Tasmania* 136: 35–38. ISSN 0080–4703. Forensic Consultant, GPO Box 1384, Hobart, Tasmania 7001, Australia (JCP); Kimberley, Tasmania 7304 (AJD); Biotechnology Division, University of Arizona, Tucson, USA (AJR); Max Plank Institute for Evolutionary Anthropology, Molecular Anthropology Group, Leipzig, Germany (MS).

The hyper-variable control region (HV1 and HVII) of mitochondrial DNA (mtDNA) from Tasmanians with an unbroken, direct Tasmanian Aboriginal maternal lineage were DNA sequenced. The lineage dates back to the early 1800s, as evidenced by published family genealogies (Mollison 1978, Ryan 1981, Plomley 1966, 1971, 1987, 1990).

Of the five distinct mtDNA haplotypes discovered, V1 was found in living Tasmanian descendants traced back to a Port Phillip Aboriginal woman who lived with European sealers in Bass Strait. Haplotype T2 is two nucleotide transitions removed from 1/WD 2 of van Holst Pellekaan *et al.* 1998 and therefore related to this Australian mainland Aboriginal mtDNA haplotype.

Vestiges of Tasmanian maternal mtDNA haplotypes from before white settlement, passing down through up to eight generations, still survive in Tasmania. The Tasmanian Aboriginal people are related and relatable to mainland Aboriginal people.

Key Words: aborigine, Tasmania, Victoria, mitochondrial DNA, maternal lineage.

BACKGROUND

In May 1987, a female Tasmanian Aboriginal elder was sexually assaulted and stabbed to death in her home in Hobart. In the subsequent police investigation, forensic blood-marker screening using phosphoglucomutase typing by isoelectric focusing, followed by nuclear DNA testing by Cellmark Corporation (UK) of the semen component from the rape kit swabs led to the conviction of a young male relative. This was the first 'cold hit' DNA match in Australia and almost the only evidence against the perpetrator. After the criminal court appeals were over in 1990, the local Tasmanian Aboriginal community awarded the investigation team an inscribed plaque and written vote of thanks (*The Mercury*, Hobart 1990).

In order to strengthen a prosecution case based almost solely on novel nuclear DNA evidence, it was decided to investigate possible additional evidence from human mitochondrial DNA sequences. This line of investigation was not completed for this case and not used in trial evidence. However, in view of the forensic potential of mitochondrial DNA databases in cases of missing persons presenting as skeletal remains only and in trace evidence with no nuclear DNA material (such as 'fallen' human hair fibres), blood samples from this case and other cases were included in a Tasmanian mitochondrial DNA database project.

MITOCHONDRIAL DNA

Most of the DNA in human cells is contained within the 46 chromosomes in the nucleus. Mitochondria, which are sub-cellular organelles found outside the nucleus in the cytoplasm, contain an extra chromosomal genome separate and distinct from the nuclear genome. Human mtDNA differs from nuclear DNA in the following ways:

1. It is a very much smaller (about 16,500 bases long), closed (circular) genome more similar to that of bacteria than to the fragile, extended, linear arrangement of nuclear chromosomes of multicellular organisms.

2. mtDNA is present in high copy numbers per cell: on average, approximately one thousand times the nuclear number.

3. mtDNA is compact, coding only for two ribosomal RNAs, 22 transfer RNAs, 13 proteins and a non-coding region about 1100 bp long, called the "displacement loop" (D-loop) or "control region". The hyper-variable D-loop region includes HV1 16024–16383 and HVII 57–372. The primers used in this study are those used by Vigilant *et al.* (1989) amplifying from 15996 to 16401 (HVI) and from 29 to 408 (HVII).

4. Human mtDNA has two separate origins of replication. The origin of H-strand or leading strand replication (OH) is located in the displacement loop region, while the origin of L-strand or lagging strand replication (OL) is within a cluster of five transfer RNA genes. Replication of mtDNA is initiated at OH. It requires both RNA synthesis and subsequent processing events to prime DNA synthesis. When the H-strand has elongated to two-thirds of its total length, OL is exposed and sponsors initiation of L-strand replication.

5. The displacement-loop (D-loop) region is the control site for both transcription and replication of mtDNA. Each strand of mtDNA contains a major dedicated promoter (the H-strand promoter) and the L-strand promoter. The L-strand promoter serves two purposes. It is the promoter for one protein and eight transfer RNA genes, and transcripts initiated here are used as primers for H-strand mtDNA replication. The transitions from RNA to DNA synthesis occur over a region of short, conserved sequences termed "conserved sequence blocks" (CSB I–III). There are no introns in mtDNA (Clayton 1992).

6. mtDNA is inherited maternally. Apart from mutational changes, it is identical for siblings and all their maternal relatives. This monoclonal nature simplifies DNA sequencing. Until recently, mtDNA was thought not to

* Aboriginal Elder, descendant of Mannalargenna and Tanleeboneyer.

undergo recombination and therefore to be inherited only in the maternal line (Gyllensten *et al.* 1991). However, this has recently been a subject of debate (Awadella *et al.* 1999, Kumar *et al.* 2000, Parson & Irwin 2000, Elson *et al.* 2001).

Heteroplasmy (Gill *et al.* 1995, Allen *et al.* 1997) is a condition where more than one single mtDNA sequence is observed in an individual. Generally, heteroplasmic mtDNA sequences differ at a single nucleotide site within an individual. Length variation has been observed in the HV1 region (Bendell & Sykes 1995) and in the HVII region (Stewart *et al.* 2001). Heteroplasmy is constant in the control region over the life of the individual (Tully *et al.* 2000, Lagerstrom-Fermer *et al.* 2001).

7. The mutation rate for mtDNA is five to ten times that of single-copy nuclear genes, due to the low fidelity of the specific mtDNA polymerase and the apparent lack of mtDNA repair mechanisms (Wolstenholme & Jeon 1992).

MATERIALS AND METHODS

Mitochondrial DNA was isolated from whole blood samples dried onto sterile cotton cloth. It was extracted with the IsoQuick kit (ORCA Research Inc Bothell, WA 98021 USA CN MXT–020–100) and sequenced for both HV1 and HVII regions. DNA sequencing of PCR products with biotinylated primers was performed as described by Redd *et al.* (1995).

RESULTS AND DISCUSSION

The alignment of the DNA sequences in table 1 is according to the revised CRS of Andrews *et al.* (2000). The Human Genome Project could be considered to have begun with the publication of the complete sequence of human mitochondrial DNA (Anderson *et al.* 1981). However, the original mtDNA reference sequence has been shown to contain both errors and rare polymorphisms (Andrews *et al.* 2000). As table 1 relates to comparisons within indigenous Australia, the common European, but not global, sites HVII 073 and HVII 263 have been rendered in half-tone.

Using published Tasmanian Aboriginal lineage data (Mollison *et al.* 1978, Ryan 1981, Plomley 1966, 1971, 1987, 1990) and comparisons with published studies of Australian mainland Aboriginal mtDNA (Van Holst Pellekaan *et al.* 1998, Redd *et al.* 1999, Huoponen *et al.* 2001), 13 unusual control-region mtDNA sequences were found in the 19 individuals tested. Six were assigned to European descent. The remaining 13 fell into five distinct groups: T1A, T1B, T2, T3 and V1 (see table 1).

Haplotype V1 was found in living Tasmanian descendants of an abducted Port Phillip (Victorian) Aboriginal woman "Granny Betty". V1 is similar to 23/Western Desert 12 of the Australian mainland Aboriginal mtDNA HVI sequences listed in van Holst Pellekaan *et al.* 1998 and for HVII as well (van Holst Pellekaan 2002, pers. comm.).

Haplotype T1A and related sequence T1B are the most remote of the sequences found when compared to van Holst Pellekaan *et al.* (1998) for HVI and HVII (van Holst Pellekaan 2002, pers. comm.).

Haplotype T2 is two nucleotide transitions different from 1/Western Desert 2 of van Holst Pellekaan *et al.* (1998) for HV1 and matching for HVII (van Holst Pellekaan 2002, pers. comm.).

Haplotype T3 may be distantly related to V1.

The nucleotide cytosine or 'C' at position 146 in HVII may be an indicator of Tasmanian origin. It is found in 17% of the 47 HVII of mainland Aborigines (van Holst Pellekaan 2002, pers. comm.), but in all but one (T3) of the small sample of haplotypes from indigenous Tasmanians. Meyer *et al.* (1999) found that this position mutates six times faster than the rest of HVII, which suggests that many more indigenous Tasmanian direct-descent examples and also known pre-settlement samples need to be analysed to resolve this question.

The global human evolutionary comparisons of mtDNA sequences are now based on comparisons of the complete mtDNA sequence, with analysis of the longer coding region (Ingman *et al.* 2000). The hyper-variable regions of mtDNA HV1 and HVII mutate at a faster and more variable rate than the coding region, and so are less useful for global comparisons but are useful for comparisons with Australia or Sahul (Stoneking 2000).

A search for, and analysis of, the non-recombining DNA section of the male Y chromosome 21 (Redd *et al.* 2002) from non-interrupted paternal Tasmanian lineages should also throw light on the relationship between the Tasmanian and Australian indigenous peoples.

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TABLE 1
Variable mtDNA nucleotide sites D-loop HVI and HVII; Tasmanian Aboriginal descent

	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1													
	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6													
	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3	0	1	1	1	1	1	1	2	2	2	2	2	2	3	3
	4	6	7	1	2	6	6	7	8	8	8	9	0	2	2	9	9	0	0	1	4	4	5	6	7	4	5	5	8	8	9	0	1	6	7	8	8	0	1
	8	9	5	1	6	3	9	2	4	6	9	2	9	3	4	1	4	1	4	1	3	6	6	2	3	6	0	2	5	9	5	7	5	3	1	6	9	2	0
																																					.	.
																																					5	5
CRS (Anderson *et al.* 1981)	G	C	T	C	T	A	C	T	C	C	T	C	T	C	T	C	C	C	T	T	A	C	T	T	A	T	C	T	G	A	T	G	A	A	C	A	C	-	-
Tasmanian Aboriginal descent																																							
lineage Worekerneemerunner 1	.	.	.	T	.	.	T	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
lineage Worekerneemerunner 2	.	.	.	T	.	.	T	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
lineage Worekerneemerunner 3	.	.	.	T	.	.	T	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
lineage Worekerneemerunner 4	.	.	.	T	.	.	T	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
T1A Cape Portland tribe																																							
lineage Wyerlooberer 1	.	.	.	T	.	.	T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
lineage Wyerlooberer 2	.	.	.	T	.	.	T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	C	G	C	.	.	.	.	.	.	.	G	.	.	.	.	C
T1B Pipers River tribe																																							
lineage Tanleeboneyer 1	.	.	C	.	.	.	.	C	.	.	.	.	.	T	.	.	.	T	.	C	.	.	.	.	G	C	G	.	.	G	.	A	G	G	G	-	.	C	C
lineage Tanleeboneyer 2	.	.	C	.	.	.	.	C	.	.	.	.	.	T	.	.	.	T	.	C	.	.	.	.	G	C	G	.	.	G	.	A	G	G	G	-	.	C	C
lineage Tanleeboneyer 3	.	.	C	.	.	.	.	C	.	.	.	.	.	T	.	.	.	T	.	C	.	.	.	.	G	C	G	.	.	G	.	A	G	G	G	-	.	C	C
T2 Little Swanport tribe.																																							
V1 Victorian Aboriginal descent																																							
lineage Elizabeth "Granny Betty" 1	.	.	.	.	.	.	.	.	T	.	.	.	C	.	.	.	.	.	.	.	.	T	.	C	G	.	.	C	.	.	C	.	.	G	.	.	.	C	C
lineage Elizabeth "Granny Betty" 2	.	.	.	.	.	.	.	.	T	.	.	.	C	.	.	.	.	.	.	.	.	T	.	C	G	.	.	C	.	.	C	.	.	G	.	.	.	C	C
lineage Fanny Cochrane 1	.	.	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	G	.	.	C	.	.	C	.	.	G	.	.	.	.	C
lineage Fanny Cochrane 2	.	.	.	.	.	.	.	.	T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	G	.	.	C	.	.	C	.	.	G	.	.	.	.	C
T3																																							

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(accepted 29 July 2002)

TWO NEW SPECIES OF *OXYETHIRA* EATON (HYDROPTILIDAE: TRICHOPTERA: INSECTA) FOR TASMANIA

by Alice Wells

(with one text-figure)

WELLS, A., 2002 (31:xii): Two new species of *Oxyethira* Eaton (Hydroptilidae: Trichoptera: Insecta) for Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 136: 39–41. ISSN 0080–4703. Australian Biological Resources Study, Environment Australia, Canberra 2601, Australia.

Two new species collected recently from the World Heritage Area of Tasmania, are described in the microcaddisfly genus *Oxyethira* (Hydroptilidae: Trichoptera: Insecta). In addition, new records are given for *Tricholeiochiton pennyae*, biogeographically one of the more enigmatic Tasmanian hydroptilid species, and for *Oxyethira tasmaniensis*, both also known only from the Tasmanian World Heritage Area.
Key Words: Tasmanian Trichoptera, new species, Hydroptilidae.

INTRODUCTION

Survey work in the Tasmanian World Heritage Area of southwestern Tasmania, using a combination of sweep-netting and pitfall-trapping, continues to yield new Trichoptera species, and to provide further data on others. Newly described here are two species of *Oxyethira* Eaton, *O. driesseni* and *O. torquata*, both of which conform in general features with members of subgenus *Trichoglene*.

Only two other hydroptilid species were taken with these new species. Both *Oxyethira (Trichoglene) tasmaniensis* Wells and *Tricholeiochiton pennyae* Wells were described from the World Heritage Area (Wells 1998) and, given the quite intensive collecting effort elsewhere in Tasmania, it is highly probable that all four species reported here are restricted to the World Heritage Area. Moreover, *T. pennyae* may exhibit behaviour atypical of hydroptilids. The bodies of both males and females of this species are unusually sturdy looking, and generally far more heavily sclerotised than is normal in the family. These features, coupled with the prevalence of this species in pitfall traps, suggest that *T. pennyae* may be far less able, or less likely, to fly than most other microcaddisflies. Given this possibility and the curious occurrence of this species so far south, with its closest congener in northeastern Queensland (Wells, 1998), this species warrants further investigation.

Depository institutions are abbreviated as follows: ANIC – Australian National Insect Collection, Canberra; NMV – Museum Victoria, Melbourne. Distribution refers to the provinces as used by Neboiss (1977).

DESCRIPTIONS

Oxyethira (Trichoglene) driesseni Wells, 2002 Fig. 1A–C

Material examined

Holotype ♂ Tasmania, Lake St Clair, Site RCE young, 17 Jan. 2000, ANIC. Paratypes: 3♂ ♀ Tasmania, Lake St Clair, Site RCW old, 17 Jan. 2000, ANIC, NMV (1♂); ♀ Lake St Clair, Site SCRW, 25 Nov. 2000, ANIC.

Length of forewing: ♂ 2.0–2.2 mm. Resembling *Oxyethira columba* (Neboiss, 1977) and *O. mienica* Wells, 1981 in general form of male genitalia, but clearly distinguished from both by the greatly developed dorso-lateral processes tipped by an incurved hook above a tuft of setae and by tergite X, which is apically acuminate.

Male genitalia (Fig. 1A–C) segment IX concave apico-ventrally, produced posteriorly at dorso-lateral angles to form two processes, the most ventral of which is hooked apically and bears a tuft of setae subapically; dorsal plate (tergite IX) tapered sharply towards acuminate apex, a group of four papillae subapically on dorsal surface; inferior appendages reduced to small lobes, bearing a pair of setae apically; subgenital plate about as long as inferior appendages, membranous, with a long seta at each apico-lateral angle; phallus extremely long, apically expanded and bearing a lateral spine.

Etymology

Named for Michael Driessen, whose collecting in the Tasmanian World Heritage Area has made a considerable contribution to knowledge of the Tasmanian fauna.

Distribution

Tasmania, C province. Known only from type locality. Tasmanian endemic.

Oxyethira (Trichoglene) torquata Wells, sp. nov. Fig. 1D–F

Material examined

Holotype: ♂ Tasmania, McPartlan Pass, Site 8A, 7 Mar. 2000, M. Driessen, ANIC. Paratypes: ♂ same data as for holotype, 8 Mar. 2000, NMV; E McPartlan Pass, Site 4B, 8 Mar. 2000, M. Driessen, ANIC; ♂ McPartlan Pass, Site 10B, 8 Mar. 2000, M. Driessen, ANIC; ♂ E McPartlan Pass, Site 1D, 14 Mar. 2000, M. Driessen, NMV; E McPartlan Pass, Site 9K, 15 Mar. 2000, M. Driessen, ANIC; ♀ McPartlan Pass, Site TRE O, 4 April 2000, M. Driessen, ANIC; ♂ McPartlan Pass, Site TRW Y, 4 April 2000, M. Driessen, ANIC; ♂ McPartlan Pass, Site 9A, 7 [month not

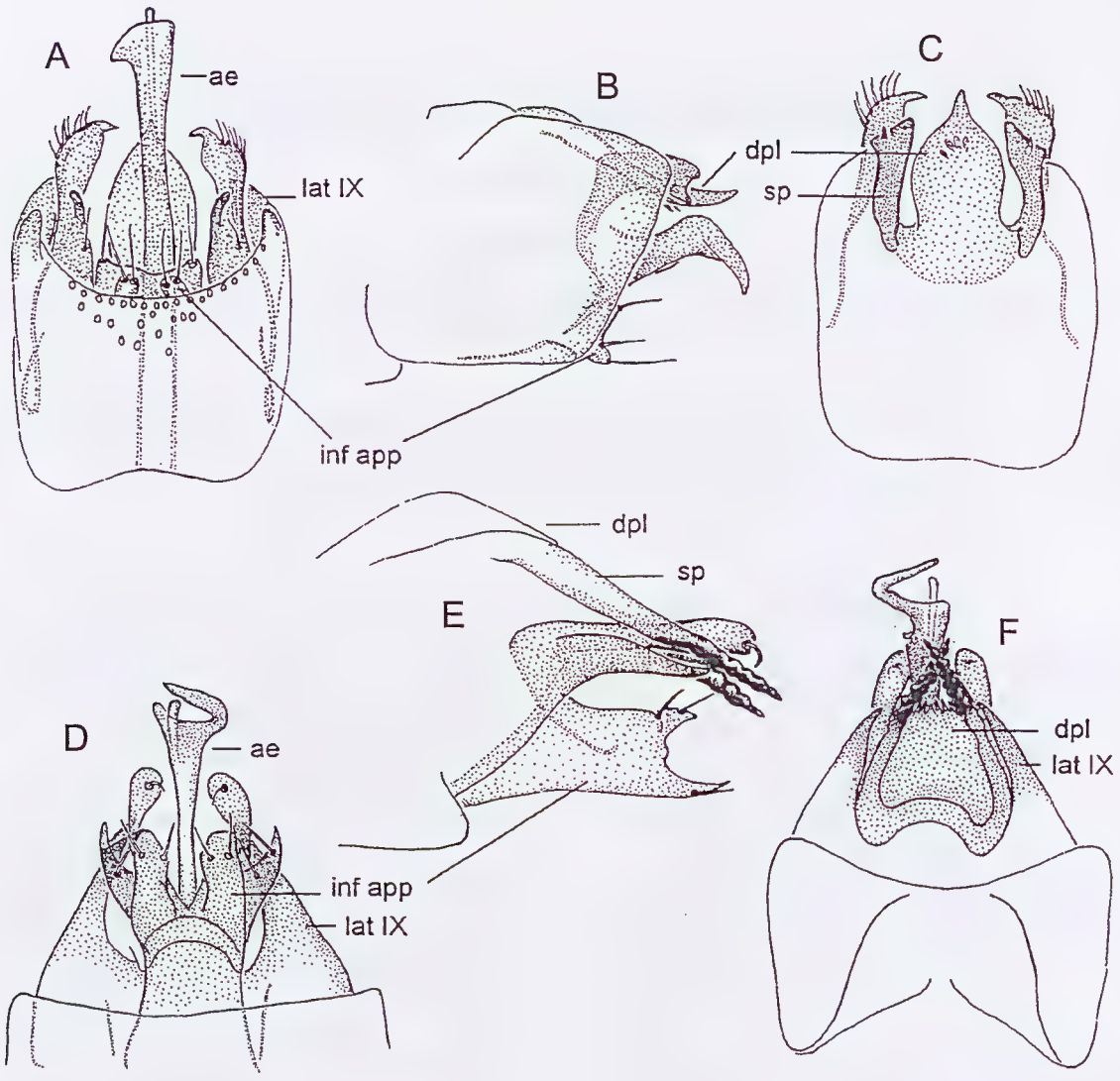

Fig. 1 — (A–C) Oxyethira (Trichoglene) driesseni *sp. nov., male genitalia: A, ventral; B, lateral; C, dorsal views. (D–F)* Oxyethira (Trichoglene) torquata *sp. nov., male genitalia; D, ventral; E, lateral; F, dorsal views. Abbreviations: ae, aedeagus; dpl, dorsal plate; inf app, inferior appendages; lat IX, lateral lobes of abdominal segment IX; sp, lateral spine on dorsal plate.*

recorded] 2001, M. Driessen, ANIC; ♂ Airstrip Road Site 1B, 8 Mar. 2000, M. Driessen, ANIC.

Length of forewing: ♂ 1.8–1.9 mm. Distinguished from all other Tasmanian hydroptilids by the twisted, sclerotised lateral spines of the dorsal plate in the male genitalia.

Male genitalia (Fig. 1D–F) with segment IX wider than long ventrally and dorsally, but produced laterally to about length of genitalic parts; dorsal plate (tergite X) a membranous median plate flanked by a pair of darkly sclerotised, twisted spines; inferior appendages stoutly bilobed, the ventral lobe membranous, with subapical setae, the lateral lobe a pale spur; subgenital plate appears to be represented by a pair of elongate, distally swollen lobes, each with a seta apically; phallus slender, with a sharply hooked spine apically.

Etymology

Named for the twisted form of the lateral processes of dorsal plate.

Distribution

Tasmania, Central province. Known only from type locality. Tasmanian endemic.

Oxyethira (Trichoglene) tasmaniensis Wells

Oxyethira (Trichoglene) tasmaniensis Wells, 1998: 83.

Holotype ♂ Tasmanian World Heritage Area, Southwest National Park, Melaleuca, 43°25'10"S 146°08'46"E, (ANIC).

Material examined
2♂ 2♀ McPartlan Pass, Mar. 2000, Mar., April 2001.

Distribution
Tasmania, Central province. Tasmanian endemic.

Tricholeiochiton pennyae Wells

Tricholeiochiton pennyae Wells 1998: 82

Holotype ♂ Tasmanian World Heritage Area, Southwest National Park, Melaleuca, 43°31'00"S 146°09'41"E, (ANIC).

Material examined
8♂ 8♀ King William Creek, Feb. 1999, Feb.–Mar. 2001; numerous ♂ ♀ Lake St Clair, Mar. 1999, Jan., Mar., Nov. 2000; numerous ♂ ♀ McPartlan Pass, Mar. 1999, Mar., April 2000; numerous ♂ ♀ Airstrip Road, 1999, Mar. 2000.

Distribution
Tasmania, Central province. Tasmanian endemic.

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(accepted 9 September 2002)

NEW GENERA AND SPECIES, AND NEW RECORDS, OF TASMANIAN TRICHOPTERA (INSECTA)

by Arturs Neboiss

(with 28 text-figures)

Neboiss, A., 2002 (31:xii): New genera and species, and new records of Tasmanian Trichoptera (Insecta). *Papers and Proceedings of the Royal Society of Tasmania* 136: 43–82. ISSN 0080 4703. Department of Entomology, Museum Victoria, Melbourne 3001, Australia.

Examination of Trichoptera specimens collected in Tasmania over the last 25 years has led to a revision of the Trichoptera list for Tasmania, and expansion of the distributions of many species, particularly those in the World Heritage areas. The following 17 new species are described: *Poecilochorema anastemum, Taschorema dispatens, Ptychobiosis iconica, Chimarra derogata, Hydrobiosella tahunense, H. anatolica, H. disrupta, H. propinqua, H. scalaris, H. otaria, Daternomina quastrulla, D. jacksonae, Cheumatopsyche deani, C. alampeta, Diemeniluma serrula, Marilia aenigmata* and *Tasmanthrus gwendolensis.* There are also three new combinations — *Taschorema ithyphallicum* Schmid, *Daternomina irrorata* Kimmins and *Diemeniluma tasmanica* Jacquemart. New genera are established for *Daternomina* (Family Ecnomidae) and *Diemeniluma* (Family Hydropsychidae).

Key Words: Trichoptera, Tasmanian World Heritage areas, classification, new genera and species.

INTRODUCTION

The present study of Tasmanian caddisflies (Trichoptera) introduces new genera and species and extends distributions of previously recorded species. It results from evaluation of material accumulated during the last 25 years, during which time, considerable effort has been spent investigating the Tasmanian World Heritage areas (Dean & Cartwright 1992, Jackson 1999, 2000). Over this period, too, there have been dramatic changes to the environment, particularly to the water systems associated with the Gordon River dam, and, significantly, some of the species included in this study are currently listed in the *Threatened Species Protection Act 1995* (Tas). In addition, further development and analyses of Trichoptera systematics (Neboiss 1986, Schmid 1989) have led to taxonomic changes that impinge on the Tasmanian Trichoptera faunal list, necessitating a reassessment of the generic and specific status of several species. With the description here of two new genera, *Daternomina* (Family Ecnomidae) and *Diemeniluma* (Family Hydropsychidae), and 17 new species, the Tasmanian fauna now totals 189 species in 74 genera. New information is given on species' distributions.

MATERIAL AND METHODS

All specimens are preserved in 75% ethanol; if detailed examination was required, abdomens were cleared in KOH solution and then transferred to glycerol for drawing and storage. Dissected specimens are identified by the author's notebook number with the prefix 'PT-'. All examined material is in the Museum Victoria collection, Melbourne (NMV), unless otherwise indicated. Other depository institutions are identified as follows: ANIC — Australian National Insect Collection, Canberra; BMNH — The Natural History Museum, London (= NMH); IRScNB — Institut Royal des Sciences Naturelles de Belgique, Brussels; QM — Queensland Museum, Brisbane; and SAM — South Australian Museum, Adelaide.

FAMILY HYDROBIOSIDAE

The family Hydrobiosidae was revised by Schmid (1989), who regarded it as a primitive family of Gondwanan origin. Schmid, however, admitted that the phylogeny could not be reconstructed, and placed hydrobiosids, with uncertainty, at several positions in the Annulipalpia branch (Schmid 1989: fig. 33). In the same work, Schmid described several new species from Tasmania and split the genus *Austrochorema* Mosely into two separate genera: *Austrochorema* s.l., and *Poecilochorema* Schmid, a genus endemic to Tasmania. Further changes proposed here include the referral of Tasmanian specimens previously identified as *Ptychobiosis nigrita* Banks to a new species – *iconica*; transfer of *Ethochorema ithyphallicum* Schmid to the genus *Taschorema*; and description of another new species, *dispatens.*

Genus *Allochorema* Mosely

Allochorema Mosely *in* Mosely & Kimmins, 1953: 491; Neboiss 1977: 13.
Type species: *Allochorema tasmanica* Mosely, by original designation.

Allochorema tasmanicum Mosely

Allochorema tasmanica Mosely *in* Mosely & Kimmins, 1953: 491; Neboiss 1977: 13.

Holotype

♂ Tasmania, Mt Wellington, alt. 3000 ft, Dec. 1937 (BMNH).

Additional material examined

♂ Hartz Mountains National Park, 1977, J, Sedlacek; 4♂ Strathgordon, Jan. 1977, J. Sedlacek; 1♂ d'Entrecasteaux River source, below Mt LaPerouse, alt. 840 m; 43°30'S 146°44'E, 15 Feb. 1988, P.B. McQuillan; 3♂ Lake Tahune, Frenchmans Cap area, 28 Jan. 1988, J. Jackson; 1♂ Lake Pedder, shore N of Forest Creek, 10 Feb. 1999, J. Jackson;

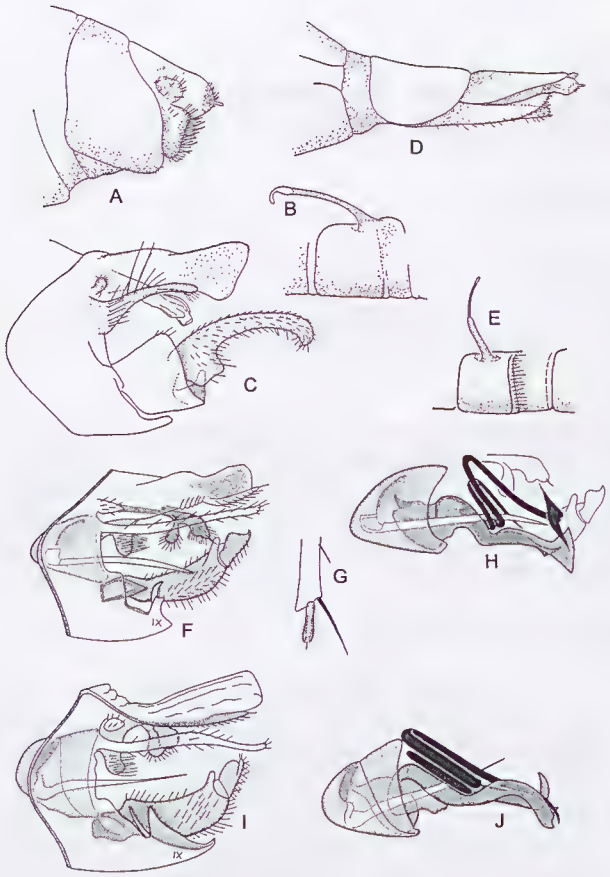

FIG. 1 — (A–C) Austrochorema pegidion: *(A) female genitalia lateral; (B) male lateral filament of sternite V; (C) male genitalia lateral (phallic apparatus omitted); (D)* Poecilochorema crinitum, *female genitalia lateral.; (E)* Poecilochorema evansi, *male lateral filament of sternite V; (F–H)* Poecilochorema complexum: *(F) male genitalia lateral (phallic apparatus omitted); (G) phallic apparatus lateral; (H) modified spur on male hind tibia; (I, J)* Poecilochorema circumvolutum: *(I) male genitalia lateral; (J) phallic apparatus lateral.*

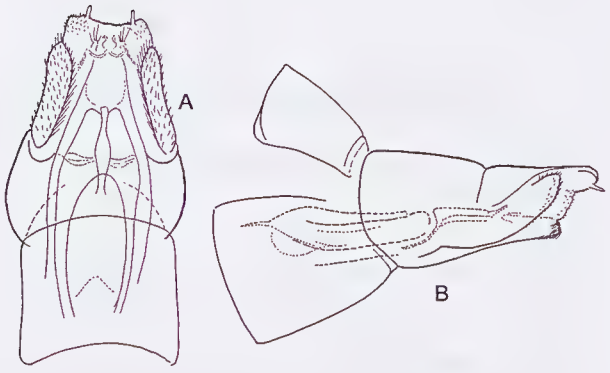

FIG. 3 — Poecilochorema anastemum *female genitalia: (A) ventral, (B) lateral.*

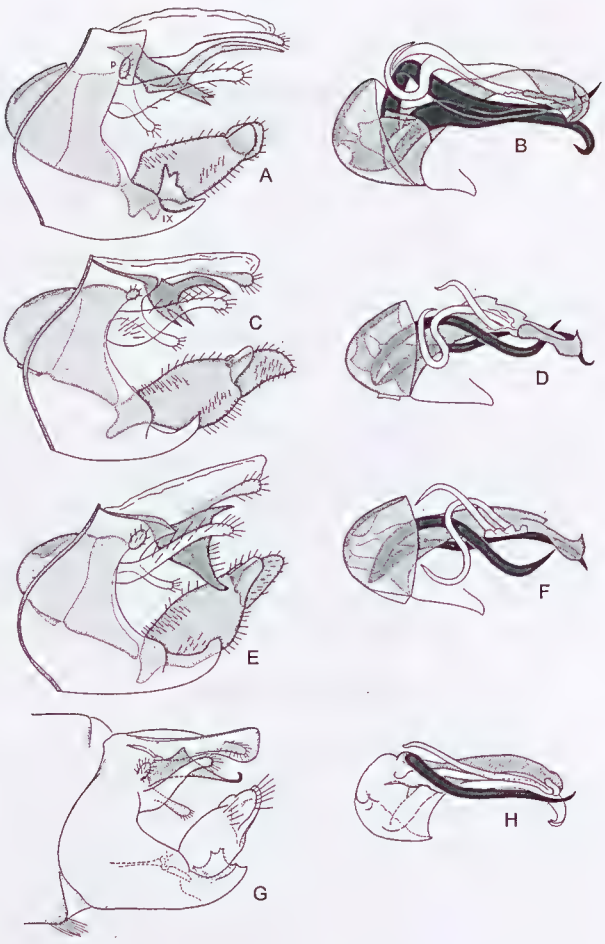

FIG. 2 — (A, B) Poecilochorema evansi*: (A) male genitalia lateral; (B) phallic apparatus lateral; (C, D)* Poecilochorema crinitum*: (C) male genitalia lateral; (D) phallic apparatus lateral; (E, F)* Poecilochorema lepnevae*: (E) male genitalia lateral; (F) phallic apparatus lateral; (G, H)* Poecilochorema anastemum *sp. n.: (G) male genitalia lateral; (H) phallic apparatus lateral.*

1♂ Lake Pedder, Frankland shore, 10 Feb. 1999, J. Jackson; 1♂ Lake Oberon, Western Arthur Ranges, top of plain, 9 Mar. 1999, J. Jackson. All specimens in NMV.

These additional locality records indicate that this species has a wider distribution throughout the southwest of Tasmania than believed previously.

Distribution

Tasmania. Not recorded from other states.

Genus *Austrochorema* Mosely

Austrochorema Mosely *in* Mosely & Kimmins, 1953: 481; Neboiss 1977: 14; Schmid 1989: 76.

Type species

Austrochorema wenta Mosely, by original designation.

Two species groups were recognised by Neboiss (1977), distinguished by differences in male and female genitalic

structures. In one group, the male genitalia have the inferior appendages with coxopodite short and the terminal segments of the female abdomen short (fig. 1A). The main distribution of this group is on the Australian mainland, with the exception of one species — *Austrochorema pegidion* Neboiss, which is the only species present in Tasmania. The six other species, all having the coxopodite long in male genitalia and terminal segments elongate and dorsoventrally compressed in the female, constitute the second group. Schmid (1989) analysed these two groups in detail, considering them to be two distinct genera. *Poecilochorema* included five endemic Tasmanian species. Here another new species is added to this genus.

Austrochorema pegidion Neboiss
Figs 1A–C, 4A

Austrochorema pegidion Neboiss, 1962: 535; Neboiss 1977: 15.

Holotype
♂ Tasmania, Broad River nr Lake Dobson, Mt Field National Park, 6 Nov. 1955 (NMV).

Additional localities
1♂ Lake Tahune, Frenchmans Cap area, 29 Jan. 1988, J. Jackson; 1♂ Lake Nancy, Frenchmans Cap area, 28 Jan. 1988, J. Jackson; 1♂ unnamed creek, Overland track approx. 1.5 km NW of Pelion Gap, Cradle Mountain-Lake St Clair National Park, 17. Jan. 1990, J. Dean and D. Cartwright; 1♂ Mt Barrow, 11 km EbyN Nunamara, 30 Jan. 1983, J. Cardale (male genitalia prep. PT-2132 illustrated). All specimens in NMV.

Larvae, identified by J. Dean, have been recorded from the following localities: Mt Wellington below Organ Pipes, 21 Sept. 1978; N of Savage River on pipeline, 11 May 1975; Dip River Falls, 27 Feb. 1982; St Columba Falls, 10 Mar. 1982; Rafferty Creek, Ben Lomond National Park, 25 Jan. 1990; Port Davey Track, 2 miles W of Picton River, 11 Feb. 1966; Flinders Island, Mt Strzelecki, Creek off main road, 19 Oct. 1996. All specimens in NMV.

Distribution
Tasmania. Tasmanian endemic.

Genus *Poecilochorema* Schmid

Poecilochorema Schmid, 1989: 77.

Type species
Anachorema evansi Mosely, 1953 by original designation.

This genus was described in great detail by Schmid (1989), and thus only a short diagnosis is given here.

Diagnosis
Forewing discoidal cell short, open; fork 4 with long footstalk; hind wing fork 1 with long footstalk, fork 2 with short footstalk. In the male, abdominal sternite V the lateral filament (fig. 1E) has only basal half sclerotised, distal part filiform; inferior appendages with coxopodite longer than harpago; phallic apparatus (the most complex in the family) with long, twisted processes (fig. 1G). Female abdomen (fig. 1D) with terminal segments extended distally, dorsoventrally compressed.

The five species included in the genus *Poecilochorema* by Schmid (1989) were placed in two species groups. The *complexum* group, including *complexum* (Jacquemart) and *circumvolutum* Schmid, is characterised by males with modified posterior mesal spur on hind tibia (fig. 1H) and parapodes in male genitalia developed into a pair of distally rounded lobes. In the *evansi* group, which includes *evansi* (Mosely), *crinitum* (Neboiss), *lepnaevae* (Jacquemart) and *anastemum* sp. n., the apical mesal spurs are not modified and the parapodes are pointed distally.

The known distributions of the species indicate that the genus consists of several closely related species, each with a rather restricted distribution. Illustrations of males of all species are provided to facilitate their identification. The illustrations are from Schmid (1989) and Neboiss (1977).

complexum group

Poecilochorema complexum (Jacquemart)
Figs 1F–H, 4B

Austrochorema complexa Jacquemart, 1965: 41; Neboiss 1977: 17.
Poecilochorema complexum. Schmid 1989: 134.

Holotype
♂ Tasmania, Cradle Mountain, 10 Jan. 1923 (IRScNB).

Additional localities
1♂ Lake Pedder (before flooding), 10 Mar. 1972, A. Neboiss; 1♂ Gordon River 1 km above First Split, 11 Jan. 1977, A. Neboiss; 1♂ Franklin River, Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss.

Distribution
Tasmania, NW and SW provinces, known from a few localities, rare. Tasmanian endemic.

Poecilochorema circumvolutum Schmid
Figs 1I, 1J, 4B

Poecilochorema circumvolutum Schmid, 1989: 134.

Holotype
♂ Tasmania, Sir John Falls, Cataract Creek, 9 Jan. 1977 (NMV).

Distribution
Tasmania, SW province, rare, known only from type locality. Tasmanian endemic.

evansi group

Poecilochorema evansi (Mosely)
Figs 1E, 2A, 2B, 4C

Anachorema evansi Mosely *in* Mosely & Kimmins, 1953: 460.
Austrochorema evansi. Neboiss 1962: 533; Neboiss 1977: 15.

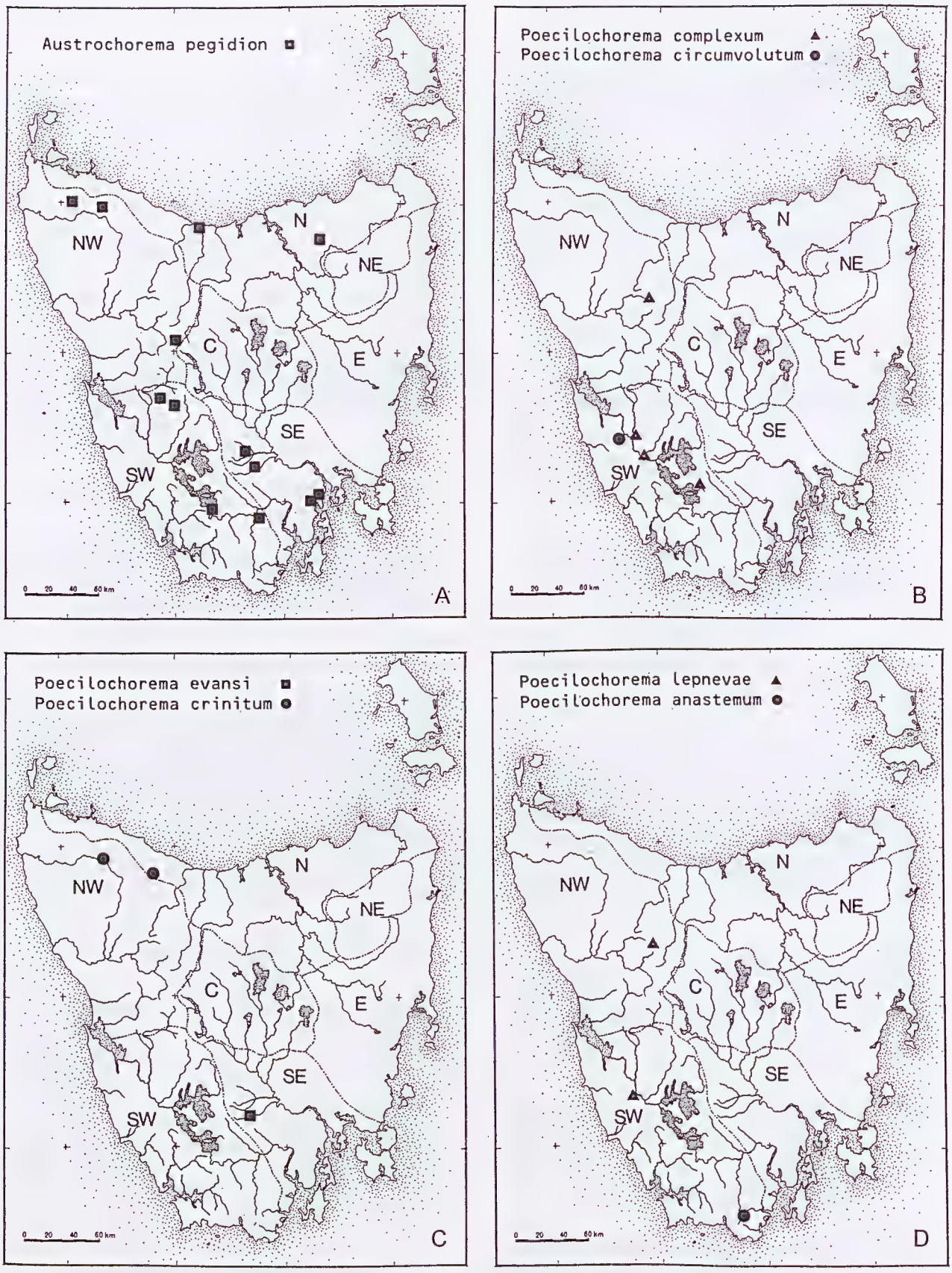

FIG. 4 — Distribution maps: (A) Austrochorema pegidion*; (B)* Poecilochorema complexum *and* P. circumvolutum*; (C)* P. evansi *and* P. crinitum*; (D)* P. lepvevae *and* P. anastemum *sp. n.*

Poecilochorema evansi. Schmid 1989: 134.

Holotype
♂ Tasmania, without definite locality or date (BMNH).

No additional material available.

Distribution
Tasmania, recorded only from Russell Falls, 23 Feb. 1967; 20 Feb. 1971; 5 Dec. 1972. Tasmanian endemic.

Poecilochorema crinitum (Neboiss) Figs 1D, 2C, 2D, 4C

Austrochorema crinitum Neboiss, 1977: 16.
Poecilochorema crinitum. Schmid 1989: 134.

Holotype
♂ Tasmania, Guide River Falls nr Ridgley, 18 Nov. 1972 (NMV).

Distribution
Tasmania, Dip River Falls near Mawbanna. No additional material available. Tasmanian endemic.

Poecilochorema lepnevae (Jacquemart) Figs 2E, 2F, 4D

Austrochorema lepnevae Jacquemart 1965: 43; Neboiss 1977: 17.
Poecilochorema lepnevae. Schmid 1989: 134.

Holotype
♂ Tasmania, Cradle Mountain, 27 Jan. 1923 (IRScNB).

Distribution
Tasmania, 15♂ Sir John Falls, Cataract Creek, 8 Jan. 1977, A. Neboiss *et al.* (may be locally common). No additional specimens available. Tasmanian endemic.

Poecilochorema anastemum sp. n. Figs 2G–3B, 4D

Type material
Holotype♂ Tasmania, below Maxwell Ridge, small tributary to Picton River, above Reservoir Lakes, 43°29'S 146°44'E, alt. 800 m (Mt LaPerouse area), 15 Feb. 1988, A. Neboiss. Paratypes 2♂ 4♀ collected with holotype (male genitalia prep. PT-2245 illustrated); 1♂ 1♀ d'Entrecasteaux River source below Mt LaPerouse, alt. 800 m, 15 Feb. 1988, A. Neboiss. All specimens in NMV.

In general appearance and size similar to the other species in the genus.

Length of forewing: ♂ 5.5–5.9 mm; ♀ 5.2–5.7 mm. The species is distinguished by details of the male genitalia.

Diagnosis
Ventral portion of segment IX rather robust, extended distally, with flat, laterally compressed, dorso-mesal projection; inferior appendages with harpago somewhat obscured by extended coxopodite; pre-anal appendages small; superior appendages (termed 'filipodes' by Schmid 1989) about 2/3 length of segment X; parapodes elongate triangular with distal angle extended into laterally curved process. This is the most important distinguishing character separating this species from *P. lepnevae.*

Female abdomen with terminal segments somewhat flattened dorso-ventrally (Fig. 3A, B).

Etymology
Anastema (Gr) — height, in reference to elevation of the type locality.

Distribution
Known only from the type locality. Tasmanian endemic.

Genus *Ethochorema* Neboiss

Ethochorema Neboiss, 1977: 24.

Type species
Taschorema nesydrion Neboiss, 1962 by original designation.

Ethochorema kelion Neboiss

Ethochorema kelion Neboiss, 1977: 26.

Holotype
♂ Tasmania, Condominion Creek, 15 Feb. 1971 (NMV). Originally this species was recorded from only two localities, but recent collections show that it is more widespread than thought previously. All localities are from the SW and NW provinces.

Additional material examined
1♂ Gordon River, creek 500 m below Second Split, 12 Jan. 1977, A. Neboiss *et al.*; 1♂ Gordon River, 1 km above First Split, 11 Jan. 1977, A. Neboiss *et al.*; 1♀ Condominion Creek, 12 Feb. 1980, K. Fairey; 1♀ same loc., 9 Feb. 1988, A. Neboiss and K. Walker; 3♂ 2♀ Franklin River, Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss *et al.*; 1♂ 2♀ Strathgordon, Jan. 1977, J. Sedlacek; 1♂ 'FERF' Kroanna Creek, Mid site, 9 Mar. 1988, SC; 1♂ Lake Nancy, Frenchmans Cap area, 28 Jan. 1988, J. Jackson; 2♂ 5♀ Lake Tahune, Frenchmans Cap area, 29 Jan. 1988, J. Jackson; 2♂ d'Entrecasteaux River source, below Mt La Perouse, alt. 840 m, 15 Feb. 1988, P.B. McQuillan. All specimens in NMV.

Distribution
Tasmania. Tasmanian endemic.

Ethochorema secutum Neboiss

Ethochorema secutum Neboiss, 1977: 24.

Holotype
♂ Tasmania, 10 miles E of Strahan, 6 Feb. 1967; ANIC

Additional localities
Tasmania, 1♂ Ropeway Creek, 400 m below Smith and Gordon River Junction, 2 Feb. 1977, Colemman & Richardson; 1♂ Lake Pedder, Frankland shore campsite, 1 Mar. 1988, J. Jackson; 1♂ Lake Pedder shore N of Forest Creek, 10 Feb. 1999, J. Jackson. All specimens in NMV.

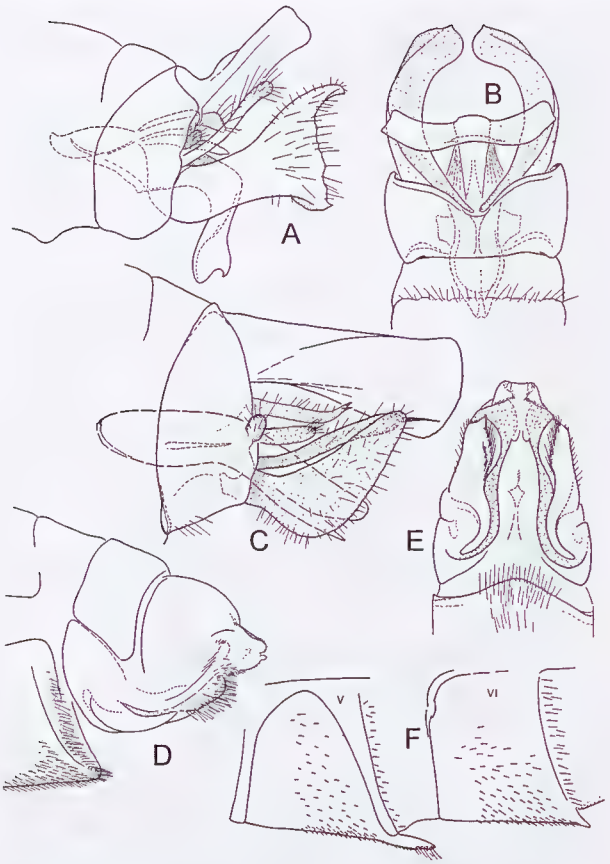

FIG. 5 — Taschorema *spp. (A, B)* Taschorema dispatens *sp. n., male genitalia: (A) lateral; (B) ventral; (C)* T. ithyphallicum, *male genitalia lateral; (D–F)* T. pedunculatum *female genitalia: (D) lateral; (E) ventral; (F) abdominal sternites V and VI lateral.*

Distribution
Tasmania, NW and SW provinces. Tasmanian endemic.

Genus *Taschorema* Mosely

Taschorema Mosely, 1936: 422.

Type species
Taschorema asmana Moseley, 1936 by original designation.

Taschorema dispatens sp. n.
Fig. 5A, B

Material examined
Holotype ♂ Tasmania, LaPerouse, source of d'Entrecasteaux River, alt. 840 m, 15 Feb. 1988, P.B. McQuillan and A. Neboiss (genitalia prep. PT-1699 illustrated), NMV.

Length of forewing: ♂ 7.5 mm.

A medium-sized species, identified by the sessile fork 1 in hind wing and a total absence of ventral processes on abdominal segments. The strongly developed inferior appendages and the absence of two long bristles on the anal margin of forewing place this species close to *Taschorema evansi* Mosely.

Male genitalia (fig. 5A, B) characterised by large, rather robust, curved inferior appendages, which in lateral view are expanded and truncate apically; segment X elongate triangular in dorsal view; pre-anal appendages very short, superior appendages shorter than inferior appendages; two pairs of processes are located, mesally of pre-anal appendages (termed 'parapodes' by Schmid 1989). The phallus is robust, apically divided into two large down-turned lateral lobes.

Female unknown.

Etymology
Dispatens (L) — opening in different directions, in reference to the shape of phallus.

Distribution
Tasmania, SW province. Known only from type locality. Tasmanian endemic.

Taschorema ithyphallicum (Schmid) comb. nov.
Fig. 5C

Ethochorema ithyphallicum Schmid, 1989: 132; Pl. XI figs 4–6.

Material examined
Holotype ♂ Tasmania, Franklin River Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, D.Coleman, A.Neboiss, P.Allbrook. Paratype 1♂ Strathgordon, Jan. 1977, J. Sedlacek, NMV.

Additional material examined
1♂ Lake Tahune, Frenchmans Cap area, 28 Jan. 1988, J. Jackson (male genitalia prep. PT-1698 illustrated).

Described by Schmid (1989), this species was placed in the genus *Ethochorema* close to *secutum* Neboiss. However, Schmid noted that the wing venation is close to that in *Taschorema evansi* Mosely. The absence of cross-vein C-Sc also agrees with the genus *Taschorema.* The wing venation is the major separating character between *Taschorema* and *Ethochorema* (Neboiss 1977). The male genitalic characters are variable in both genera and can not be used for generic identification. The species *ithyhpallicum* is therefore transferred to the genus *Taschorema.*

Diagnosis
Forewing ♂ 9.3–9.5 mm; ♀ not known. Fork 1 long, sessile, fork 4 long; anal margin without two long bristles. Hind wing with cell-like structure between Cu2 and Al; androconia present on A2 and A3.

Male genitalia (fig. 5C) segment X large, rather robust. Inferior appendages in lateral view somewhat triangular, pre-anal appendages small, rounded; superior appendages slender, about as long as inferior appendages with strong apical spine; two pairs of processes mesally (parapodes of Schmid), the upper one more sclerotised than the lower and terminating in a bipointed apex; the lower one semi-membranous, shorter and rounded apically. Phallus slightly bent downwards at middle.

Distribution
All known localities are within the Southwest World Heritage Area. Tasmanian endemic.

Taschorema pedunculatum Jacquemart
Fig. 5D–F

Taschorema pedunculata Jacquemart, 1965: 35; Neboiss 1977: 30.

Holotype
♂ Tasmania. Cradle Mountain, 12 Jan. 1923 (IRScNB).

Diagnosis of female
Abdomen (fig. 5F) with ridge on sternite V terminating at the lateral margin, ventrally developed into moderately large mesal process; a small pointed process on sternite VI; posterior margin of sternite VII covered with fine dense indistinct band of hair; segment VIII short, which together with part of segment IX forms elongate, rounded lateral pockets, visible in ventral view.

Additional localities
5♂ 4♀ Melaleuca Creek, Melaleuca, 43°25'S 146°09'E, MV-light, 12 Feb. 1988, A. Neboiss and K. Walker (female genitalia prep. PT-2255 illustrated); l♂ Lake Pedder, shore N of Forest Creek, 10 Feb. 1999, J. Jackson; 2♂ Lake Pedder, 1 Mar. 1988, J. Jackson; 2♂ 1♀ Lake Pedder, Frankland shore, 10 Feb. 1999, J. Jackson; 1♂ 3♀ Lake Pedder, Pebbly Creek south branch, 2 Mar. 1988, J. Jackson; 2♂ same loc. 10 Feb. 1999, J. Jackson; 3♂ below Maxwell Ridge, small tributary to Picton River, above Reservoir Lakes, 15 Feb. 1988, A. Neboiss; 7♂ 3♀ d'Entrecasteux River source below Mt La Perouse, alt. 800 m, 16 Feb. 1988, A. Neboiss; 1♂ 2♀ Ray River, 10 Feb. 1988, SC/PH; 1♂ Gordon River 1 km above First Split, 11 Jan. 1977, A. Neboiss; 1♂ Olga-Hardwood River saddle, buttongrass plain, 4 Mar. 1977, P. Allbrook; 1♂ Dozer Creek below Gordon road, 4 Mar. 1999, J. Jackson; 1♂ Franklin River Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss. All specimens in NMV.

Remarks
The species, previously known from very few localities, is now recorded quite widely from the SW province. It is also the first time that the female has been associated positively with the male.

Distribution
Tasmania. Tasmanian endemic.

Taschorema viridarium Neboiss

Taschorema.viridarium Neboiss, 1962: 563; Neboiss 1977: 29.

Holotype
♂ Tasmania, Broad River nr Lake Dobson, Mt Field National Park, 6 Nov. 1955 (NMV).

Additional localities
5♂ 12♀ Doctors Creek at Lake Highway near Breona, 9 Feb. 2001, R.Walker; l♂ Pinetree Rivulet nr Breona, 9 Feb. 2001, R. Walker; 1♂ 1♀ Sandfly Creek at Scotts Peak road, 9 Feb. 1988, K.Walker and J. Jackson; ♂ ♀ (numerous) d'Entrecasteaux River, South Coast road bridge, 14 Feb. 1988, A. Neboiss and K.Walker. 3♂ Old River and Collingwood River junction, 10 Feb. 1988, A. Neboiss *et al.*; l♂ Navarre River at Lyell highway, 3 Nov. 1998, J. Jackson; 1♂ Collingwood River below Lyell Highway bridge, 16 Feb. 1999, J. Jackson.

Distribution
Tasmania, widespread. Tasmanian endemic.

Genus *Ptychobiosis* Neboiss

Ptychobiosis Neboiss, 1977: 32.

Type species
Notiobiosis nigrita Banks, 1939 by original designation.

In recent years additional material and detailed studies of adults and larvae have revealed that *Ptychobiosis nigrita* (Banks) s.l. represents a species complex which is distributed from North Queensland (type locality Mt Spurgeon) along eastern Australia to Victoria and Tasmania. The small differences found in Tasmanian specimens by Neboiss (1977) were not regarded of sufficient importance for species separation. Additional information is now available and is supported by distinctive larval features as shown by Dean (1997). The Tasmanian population referred previously to the *nigrita* complex is now regarded as a distinct species.

Ptychobiosis iconica sp. n.
Fig. 6A–C

Type material
Holotype ♂ Tasmania, Olga-Hardwood River saddle, buttongrass plain, 4 Mar. 1977, P. Allbrook, J. Richardson and R. Swain. Paratypes 7♂ 1♀ collected with holotype (female genitalia prep. PT-2244 illustrated); 12♂ Strathgordon, Jan. 1977, J. Sedlacek (male genitalia prep. PT-2177 illustrated); l♂ Sandfly Creek at Scotts Peak road, 9 Feb. 1988, K. Walker, J. Jackson; 5♂ E Arthur Ranges, 1 km W of Federation Peak, alt.1000 m, 11 Feb. 1988, P. McQuillan; l♂ Lake Pedder, shore N of Forest Creek, 10 Feb. 1999, J. Jackson; l♂ Lake Pedder, S of Timber Creek, 10 Feb. 1999, J. Jackson; 2♀ Lake Pedder, Teds Beach S corner, 4 Mar. 1999, J. Jackson; 2♂ Condominion Creek at Scotts Peak road; 9 Feb. 1988, A. Neboiss, K. Walker; 3♂ Condominion Creek, 12 Feb. 1980, K. Fairy. All specimens in NMV.

Additional material examined
2♂ Cardigan River above Lyell Highway bridge, 16 Feb. 1999, J. Jackson; 4♂ Nelson River below Raglan Road bridge, 16 Feb. 1999, J. Jackson; 1♂ 1♀ Lake Tahune, Frenchmans Cap area, 28 Jan. 1988, J.Jackson; 1♀ Picton River tributary above Reservoir Lake, 43°29'S 146°441'E, alt. 800 m, 15 Feb. 1988, A. Neboiss; 3♂ Melaleuca Creek near Melaleuca, 43°25'S 146°09'E, 12 Feb. 1988, A. Neboiss, K. Walker; 2♂ 1♀ Hartz Mountains, Jan. 1977, J. Sedlacek; 3♂ d'Entrecasteaux River source, below Mt La Perouse, alt. 840 m, 15 Feb. 1988, P.B. McQuillan; 1♀ same. loc. 16 Feb. 1988, A. Neboiss; 5♂ 1♀ New River Lagoon, buttongrass, 15 Feb. 1988, J. Jackson; 2♂ Serpentine impoundment, Scotts Peak Dam, 23 Mar. 1985, P. Greenslade (NMV).

All Tasmanian specimens previously identified as *Ptychobiosis nigrita* (Banks) are now referred to *Ptychobiosis iconica.*

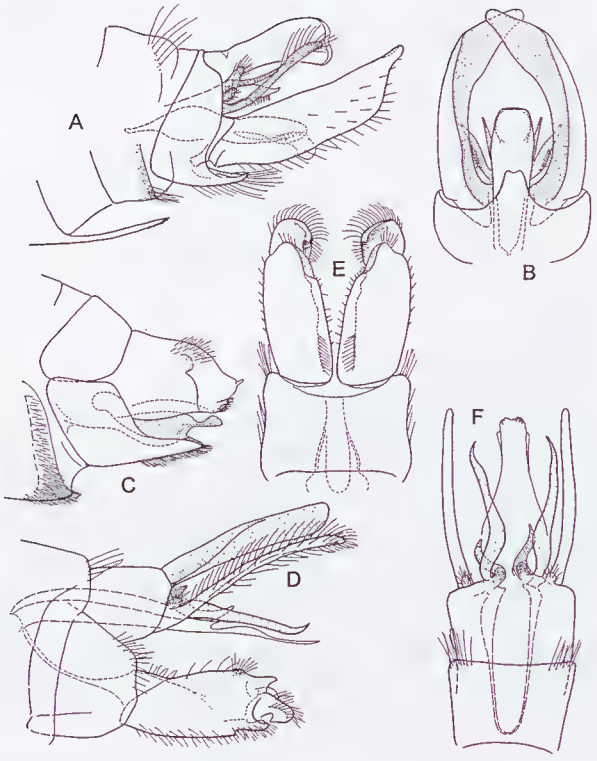

FIG. 6 — (A–C) Ptychobiosis iconica *sp. n.: (A) male genitalia lateral; (B) ventral; (C) female genitalia lateral; (D–F)* Moruya tasmanica *male genitalia: (D) lateral; (E) ventral; (F) dorsal.*

Diagnosis

Male genitalia (fig. 6A, B), segment X rather robust, the inferior appendages in ventral view curved inward, rounded apically; parapodes (= term used by Schmid 1989, upper penis cover used by Mosely & Kimmins 1953) with outer branch short, rounded; meso-ventral process of segment IX rather short, not elevated distally, much narrower than in *nigrita.*

Female genitalia (fig. 6C) sternite V with strong ventral process, sternite VI with ventral process small; sternite VII lacking process; tergite rather small, but sternite extended distally into apically rounded lip, distal end densely pubescent — in *nigrita* the lip is longer, narrower and apically truncate; terminal segment ends into two rounded lobes.

Etymology

Icon (L) — image, in reference to the resemblance to *nigrita.*

Distribution

Throughout the state of Tasmania, but more common in the western provinces. Tasmanian endemic.

Genus *Koetonga* Neboiss

Koetonga Neboiss, 1962: 567.

Type species

Koetonga clivicola Neboiss, 1962, by original designation.

Koetonga clivicola Neboiss

Koetonga clivicola Neboiss, 1962: 567; Neboiss 1977: 33; Schmid 1989: 81.

Holotype

♂ Victoria, Timbertop nr Merrijig, 5 June 1958 (ANIC).

Additional localities

Tasmania, 1♂ Sir John Falls, Cataract Creek, 9 Jan. 1977, A. Neboiss; 1♂ Dozer Creek below Gordon road, 4 Mar. 1999, J. Jackson; 7♂ 2♀ Olga River, 19 km above Gordon River junction, 13 Jan. 1977, D. Coleman and P. Allbrook; 1♀ Wedge River above Gordon road (in forest), 26 Jan. 1999, J. Jackson; 5♂ 1♀ Sandfly Creek at Scotts Peak road, 9 Feb. 1988, K. Walker and J. Jackson; 1♂ Doctors Creek at Lake Highway nr Breona, 9 Feb. 2001, R. Walker; 3♂ Port Arthur, Jan. 1977, J. Sedlacek; 2♂ 1♀ d'Entrecasteaux River at South Coast road bridge, 14 Feb 1988, A. Neboiss and K. Walker. All specimens in NMV.

Distribution

Tasmania, widespread. Other states: Victoria and New South Wales.

Genus *Moruya* Neboiss

Moruya Neboiss, 1962: 569.

Type species

Moruya charadra Neboiss, 1962 by original designation.

This endemic Tasmanian genus is represented by three closely related species. New figures are provided here for the male of *Moruya tasmanica* Jacquemart from recently collected material; the original illustrations did not show all the necessary details for positive identification. For the first time females of all three species are identified positively and a key for their separation is provided. Unfortunately, for critical separation of *charadra* and *tasmanica* it is still necessary to clear the abdomen to allow the view of vaginal sclerites.

Key to males of Tasmanian *Moruya*

1. Processes arising at the base of segment X asymmetric, shorter on one side ..... *charadra*
   Processes arising at base of segment X the same length on both sides 2
2. The short upper processes dorsally with small rounded projection at base; the long lower processes turned upward apically ..... *tasmanica*
   The short upper processes two-branched, of similar length; the long lower processes curved downward apically ..... *opora*

Key to females of Tasmanian *Moruya*

1. Abdominal cerci pigmented, dark 2
   Cerci not pigmented (fig. 7H) ..... *opora*

2. Vaginal sclerite curved (fig. 7D) ..... *charadra*
   Vaginal sclerite robust, L-shaped (fig. 7A) .... *tasmanica*

Moruya charadra Neboiss
Fig. 7D–7F

Moruya charadra Neboiss, 1962: 570; Neboiss 1977: 34; Schmid 1989: 74.

Holotype
♂ Tasmania, Broad River nr Lake Dobson, 6 Nov. 1955 (QM).

Additional material examined
Tasmania, 20♂ 30♀ Old River and Collins River junction, 43°16'S, 146°20'E, 10 Feb. 1988, A. Neboiss *et al.* (female genitalia prep. PT-2165 illustrated); 2♂ 1♀ d'Entrecasteau River source, below Mt LaPerouse, 43°30'S 146°44'E, alt. 840 m, 16 Feb. 1988, A. Neboiss and K. Walker; 1♂ 3♀ Wedge River above Gordon road, 26 Jan. 1999, J. Jackson; 15♂♀ Melaleuca Creek, near Melaleuca, 43°25'S, 146°09'E, 12 Feb. 1988, A. Neboiss and K. Walker; 1♀ Dozer Creek below Gordon road, 4 Mar. 1999, J. Jackson; l♂ below Maxwell Ridge, tributary of Picton River above Reservoir Lakes, 43°29'S, 146°44'E, 15 Feb. 1988, A. Neboiss; 1♀ Huon River below Picton River junction, 1 Feb. 1980, I. Campbell; 1♀ Hartz Creek, Hartz Mountains National Park, 25 Apr. 1974 (no collector); 1♂1♀ Navarre River at Lyell Hway, 3 Nov. 1998, J. Jackson; 1♀ Collingwood River below Lyell Highway bridge, 3 Nov. 1998, J. Jackson; 2♂ 1♀ Douglas Creek High Bridge near Old Pelion Hut, Cradle Mountain-Lake St Clair National Park, 18 Jan. 1990, J. Dean and D. Cartwright; 1♂ Gordon River 2 km below Serpentine River junction, 12 Jan. 1977, A. Neboiss; l♂ Gordon River, 1 km above First Split, 11 Jan. 1977, A. Neboiss.

Female genitalia (fig. 7D–F) characterised by pigmented cerci and vaginal sclerite gradually curved. The sclerite configuration differs from that of *M. tasmanica* by the curved upper outline visible in cleared preparation.

Distribution
Tasmania, widespread, particularly throughout western parts of the state. Tasmanian endemic.

Moruya tasmanica (Jacquemart)
Figs 6D–7C

Psyllobetina tasmanica Jacquemart, 1965: 45.
Moruya tasmanica. Neboiss 1977: 35.

Holotype
♂ Tasmania, Cradle Mountain, 27 Jan. 1923 (IRScNB).

Additional material examined
Tasmania 5♂ 4♀ Lake Tahune, Frenchmans Cap area, 29 Jan. 1988, J. Jackson (NMV). (Male and female genitalia preps PT-2166 ♂, PT-2167 ♀ illustrated.)

Male genitalia (fig. 6D–F) segment X and superior appendages about the same length and about as long as, or slightly longer than, the inferior appendages (they appear shorter in the original drawing). Small, rounded pre-anal appendages are located at the base of superior appendages. At the distal margin of tergite IX and just below segment X arise two pairs of processes (= parapodes as used by Schmid 1989), the upper process short, with dorsally elevated, rounded projection at base, twisted, unequal in length; the lower processes long, terminating with upturned, pointed apices. Inferior appendages robust, coxopodite with elongate group of strong spines on the mesal ridge near the base, harpago short with distinct curved setae apically.

Female genitalia (fig. 7A–C) with cerci pigmented, similar to those of *M. charadra*; the distal end of ovipositor appears to be somewhat more robust than in *charadra*; the vaginal sclerite in lateral view distinctly L-shaped and rather robust.

Distribution
Tasmania, restricted, known from only a few localities in C and NW provinces. Tasmanian endemic.

Moruya opora Neboiss
Fig. 7G–I

Moruya opora Neboiss 1962: 571; Neboiss 1977: 34.

Holotype
♂ Tasmania, Ouse River nr Great Lake, 2 Apr. 1960 (ANIC).

Additional material examined
Tasmania, 7♀ Lake Pedder, Serpentine boat ramp, 4 Mar. 1999, J. Jackson; 3♀ Lake Pedder, shore N of Forest Creek, 10 Feb. 1999, J. Jackson; 1♀ Lake Pedder, Teds beach S corner, 4 Mar. 1999, J. Jackson; 3♂ 10♀ Franklin River above Lyell Highway bridge, 16 Feb. 1999, J. Jackson; 1♀ Nelson River below Raglan road bridge, 16 Feb. 1999, J. Jackson; l♀ Collingwood River below Lyell Highway bridge, 3 Nov. 1998, J. Jackson; l♀, same loc., 16 Feb. 1999, J. Jackson; 4♀ Wedge River above Gordon road, 26 Jan. 1999, J. Jackson; 1♀ Huon-Picton River junction, 18 Feb. 1967, A. Neboiss (female genitalia prep. PT-2171 illustrated); 2♂ 2♀ Old River and Collins River junction, 43°16'S 146°20'E, 10 Feb. 1988, A. Neboiss *et al.*; l♀ d'Entrecasteaux River, South Cape road bridge, 14 Feb. 1988, A. Neboiss and K. Walker. All specimens in NMV.

Females of this species can be separated from the other two Tasmanian species on the basis of genitalic characteristics, namely the unpigmented cerci and basally broad vaginal sclerite (fig. 7I).

Distribution
Tasmania, widespread. Tasmanian endemic.

FAMILY HYDROPTILIDAE

The family Hydroptilidae in Australia has been extensively revised by Wells in a series of papers published between 1979 and 1998. Taxonomic problems were discussed, new species described and information given on species' distributions. Seven genera and a total of 21 species are now recorded from the island.

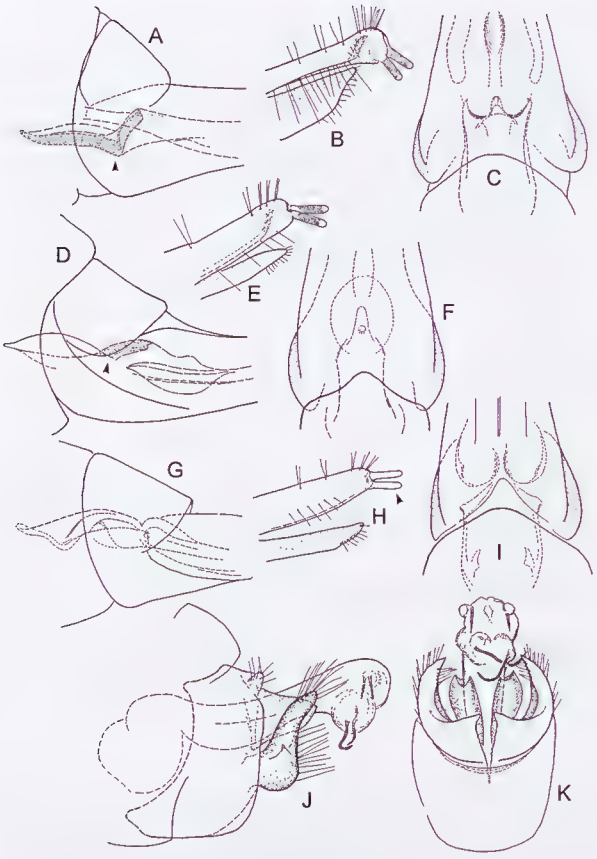

FIG. 7 — (A–I) Moruya *spp.: (A–C)* Moruya tasmanica, *female genitalia: (A) lateral; (B) tip of ovipositor; (C) ventral. (D–F)* M. charadra, *female genitalia: (D) lateral; (E) tip of ovipositor; (F) ventral. (G–I)* M. opora, *female genitalia: (G) lateral; (H) tip of ovipositor; (I) ventral; (J, K)* Chimarra derogata *sp. n., male genitalia: (J) lateral; (K) ventral.*

Genus *Hydroptila* Dalman

Hydroptila Dalman, 1819; Wells 1978: 746.

Type species
Hydroptila tineoides Dalman, 1819 by monotypy.

Hydroptila tasmanica Mosely

Hydroptila tasmanica Mosely, 1934: 147; Mosely & Kimmins 1953: 509; Neboiss 1977: 40; Wells 1978: 745.

Holotype
♂ Tasmania, Wilmot, 9 Jan. 1917 (BMNH).

Distribution
Tasmania — widespread; not recorded outside the state.

Hydroptila scamandra Neboiss

Hydroptila scamandra Neboiss, 1977: 41; Wells 1978: 751; Wells 1985: 5 (larva).

Holotype
♂ Tasmania, Scamander River, Upper Scamander, 9 Nov. 1972 (NMV).

Distribution
Tasmania — South Esk River, Evandale. Other states: widespread in eastern Victoria, New South Wales and Queensland.

Hydroptila acinacis Wells

Hydroptila acinacis Wells, 1978: 755; Wells 1985: 6 (larva).

Holotype
♂ Victoria, Koornalla, Traralgon Creek, 26 Feb. 1974 (NMV).

Distribution
Tasmania — Forth Falls; Derwent River trib. nr Gretna; Guide River Falls near Ridgley; Hellyer River Gorge. Other states: Victoria and New South Wales.

Genus *Orphninotrichia* Mosely

Orphninotrichia Mosely, 1934; Wells 1980: 628.

Type species
Orphnionotrichia maculata Mosely, 1934 by original designation.

Orphninotrichia maculata Mosely

Orphninotrichia maculata Mosely, 1934: 139; Wells 1980: 630; Wells 1985: 21 (larva).

Holotype
♂ New South Wales, Hornsby, 31 Aug. 1916 (BMNH).

Distribution
Tasmania — Wedge River; Gelignite Creek at Scotts Peak Dam road. Other states: Victoria, South Australia, New South Wales, Queensland.

Orphninotrichia acta Neboiss

Orphninotrichia acta Neboiss, 1977: 40; Wells 1980: 632.

Holotype
♂ Tasmania, Ulverstone, 18 Nov. 1972 (NMV).

Distribution
Tasmania — Forth Falls; Iris River tributary at Middlesex Plains; Broken Leg Creek at Lyell Highway. Tasmanian endemic.

Genus *Maydenoptila* Neboiss

Maydenoptila Neboiss, 1977: 44; Wells 1980: 635.

Type species
Maydenoptila cuneola Neboiss, 1977 by original designation.

Maydenoptila cuneola Neboiss

Maydenoptila cuneola Neboiss, 1977: 44; Wells 1980: 637; Wells 1985: 25 (larva).

Holotype
♂ Tasmania, Wedge River, 17 Feb. 1971 (NMV).

Distribution
Tasmania — Gordon River First Split; Murchison River; Maxwell-Denison River junction; d'Entercasteaux River; Adams Falls; Old River-Collins River junction. Other states: Victoria

Maydenoptila explicata Wells

Maydenoptila explica Wells, 1980: 639.

Holotype
♂ Tasmania — Gordon River, 1 km above First Split, 11 Jan. 1977 (NMV).

Distribution
Tasmania — Gordon River at Sprent junction; Russell Falls; Fern Creek near Rosebery; Murchison River. Not recorded outside Tasmania.

Maydenoptila rupina Neboiss

Maydenoptila rupina Neboiss, 1977: 45; Wells 1980: 643; Wells 1985: 24 (larva).

Holotype
♂ Tasmania — Guide River Falls nr Ridgley, 18 Nov. 1972 (NMV).

Distribution
Tasmania — Scamander River, Upper Scamander; Russell Falls. Other States: Victoria, South Australia.

Genus *Tricholeiochiton* Kloet & Hincks

Tricholeiochiton Kloet & Hincks, 1944: 97; Wells 1982: 252.

Type species
Leiochiton fagesii Guinard, 1878 by monotypy.

Tricholeiochiton pennyae Wells

Trichoeliochiton pennyae Wells, 1998: 81.

Holotype
♂ Tasmania – World Heritage Area, Melaleuca, 13. Feb. 1997 (ANIC).

Distribution
Tasmania — World Heritage Area, Mary Ann Creek; King Willian Creek Site; Lake St Clair; McPartlan Pass; Airstrip Road. Tasmanian endemic.

Genus *Hellyethira* Neboiss

Hellyethira Neboiss, 1977: 42; Wells 1979: 314.

Type species
Hellyethira vallecula Neboiss, 1977 (=*Xuthotrichia simplex* Mosely, 1934) by original designation.

Hellyethira simplex (Mosely)

Xuthotrichia simplex Mosely, 1934: 145.
Hellyethira vallecula Neboiss, 1977: 42.
Hellyethira simplex, Wells 1979: 315; Wells 1985: 10 (larva).

Holotype
♂ Queensland — Warwick, October (BMNH). Holotype of *H. vallecula* ♂ Tasmania, Hellyer River Gorge, 9 Feb. 1971 (NMV).

Distribution
Tasmania — E, N, NW and SW provinces. Other states: disjunct distribution ranges from northern Queensland along Great Dividing Range from northern NSW throughout Victoria, Kangaroo Island and South Australia; according to Wells (1979), this is the most abundant and widespread hydroptilid in eastern Australia.

Hellyethira basilobata Wells

Hellyethira basilobata Wells, 1979: 316; Wells 1985: 11 (larva).

Holotype
♂ Victoria, Yarra River below Upper Yarra Dam, 28 Feb. 1976 (NMV).

Distribution
Tasmania — Dip River Falls; Boyd River, Gordon road; Cardigan River at Lyell Highway; Navarre River at Lyell highway. Other states: Victoria — eastern, north-central and Otway Ranges.

Hellyethira exserta Wells

Hellyethira exserta Wells, 1979: 319; Wells 1985: 11 (larva).

Holotype
♂ New South Wales, Boonoo Boonoo River, 5 km upstream from falls, 11 Oct. 1973 (NMV).

Distribution
Tasmania — South Esk River, Evandale; Huon-Picton River junction; Sir John Falls. Other states: Victoria, South Australia.

Hellyethira malleoforma Wells

Hellyethira malleoforma Wells, 1979: 325; Wells 1985: 13 (larva).

Holotype
♂ South Australia, Uraidla, 28 Nov. 1975 (ANIC).

Distribution
Tasmania — N of Gretna. Other states: scattered throughout eastern Australia from Cairns to Birdsville in Queensland, to Bourke, NSW, Victoria and southern South Australia.

Hellyethira multilobata Wells

Hellyethira multilobata Wells, 1979: 326.

Holotype
♂ Victoria, Lake Purrumbete, 23 Feb. 1970 (ANIC).

Distribution
Tasmania — South Esk River, Evandale; Hellyer River Gorge; Lake Pedder, Teds Beach, Forest Creek and Maria Creek; Olga River; Margate. Other states: Victoria, South Australia, New South Wales.

Genus *Oxyethira* Eaton

Oxyethira Eaton, 1973: 143; Wells 1981: 104.

Type species
Hydroptila flavicornis Pictet, 1834 (= *Oxyethira costalis* Eaton, 1873) by original designation.

Oxyethira subgenus

Trichoglene Neboiss

Trichoglene Neboiss, 1977: 43.

Type species
Trichoglene columba Neboiss, 1977 by original designation.

Oxyethira (Trichoglene) columba (Neboiss)

Trichoglene columba Neboiss, 1977: 43.
Oxyethira columba Wells 1981: 160; Wells 1985: 17 (larva).
Oxyethira (Trichoglene) Wells 1987: 133.

Holotype
♂ Tasmania — Dove River, Cradle Mountain National Park, 14 Dec. 1972 (NMV).

Distribution
Tasmania — widespread throughout the state. Other states: Central Victoria, scattered localities in South Australia, New South Wales and Queensland.

Oxyethira (Trichoglene) mienica Wells

Oxyethira mienica Wells, 1981: 108.

Holotype
♂ Tasmania — Ouse River, 5 miles W of Miena, 28 Feb. 1967 (ANIC).

Distribution
Tasmania — restricted and rare. Not recorded outside Tasmania.

Oxyethira (Trichoglene) tasmaniensis Wells

Oxyethira tasmaniensis Wells, 1998: 83.

Holotype
♂ Tasmania — World Heritage Area, Melaleuca, 13 Feb. 1997 (ANIC).

Distribution
Tasmania — restricted and rare. Not recorded outside Tasmania.

Oxyethira (Trichoglene) driesseni Wells, 2002

Oxyethira (Trichoglene) driesseni Wells, 2002: 39.

Holotype
♂ Tasmania, Lake St Clair, Site RCE young, 17 Jan. 2000, ANIC.

Distribution
Tasmania, C province. Known only from type locality. Tasmanian endemic.

Oxyethira (Trichoglene) torquata Wells, 2002

Oxyethira (Trichoglene) torquata Wells, 2002: 39.

Material examined
Holotype ♂ Tasmania, McPartlan Pass, Site 8A, 7 Mar. 2000, M. Driessen, ANIC.

Distribution
Tasmania, C province. Known only from type locality. Tasmanian endemic.

Genus *Orthotrichia* Eaton

Orthotrichia Eaton, 1873: 141; Wells 1979: 586.

Type species
Hydroptila angustella McLachlan, 1865 by original designation.

Orthotrichia zonata (Neboiss)

Targatrichia zonata Neboiss, 1977: 41.
Orthotrichia zonata. Wells 1979: 591.

Holotype
♂ Tasmania, St Patricks River, Targa, 22 Feb. 1971 (NMV).

Distribution
Tasmania — widespread throughout the state. Tasmanian endemic.

Orthotrichia adornata Wells

Orthotrichia adornata Wells, 1979: 590.

Holotype
♂ Victoria, Millgrove, Yarra River, 24 Feb. 1976 (NMV).

Distribution
Tasmania — Bushy Park. Other states: Victoria, New South Wales.

FAMILY PHILOPOTAMIDAE

The family Philopotamidae is represented in mainland Australia by two genera, both of which are now also recorded from Tasmania. The genus *Chimarra* Stephens is here recorded from Tasmania for the first time and only from a single species. The genus *Hydrobiosella* Tillyard is widely distributed throughout the state. The species limitations in some cases are rather unclear and difficult to interpret.

Genus *Chimarra* Stephens

Chimarra Stephens, 1829: 318.

Type species
Phryganea marginata Linnaeus, 1767 by monotypy.

The genus *Chimarra* is well known from continental Australia from four described and a number of undescribed (now under review) species. It is here recorded for the first time from Tasmania. The only known specimen, here described as a new species, has been known for some 40 years, but its description was deferred with hopes to locate more specimens, but so far without success. The type locality near the northern end of the Great Lake was severely disturbed by road-making and repeated searches in the general area have been unsuccessful in locating further specimens.

Chimarra derogata sp. n.
Fig. 7J, K

Type material
Holotype ♂, Tasmania, Great Lake, small stream S of Breona, 27 Jan. 1960, F. McDonald (male genitalia prep. PT-802 illustrated), NMV.

Generally similar to *Chimarra monticola* Kimmins from Victoria and New South Wales, but *C. derogata* differs in details of male genitalia. The single alcohol-preserved specimen is faded and pale brownish colour, not showing any wing pattern.

Length of forewing: ♂ 6.1 mm. Spurs 1:4:4; male genitalia (Fig. 7J, K) segment IX short; superior appendages small, in lateral view elongate ovoid; segment X somewhat triangular in lateral view, only lightly sclerotised, upper margin not produced distally; inferior appendages short, abruptly curved upwards, meso-ventral angles acute triangular; phallus membranous, expanded distally, with two pairs of twisted spines internally.

Distribution
Tasmania — Central province, known from type locality only.

Etymology
Derogatus (L) — 'belittle' in reference to reduced size of segment X.

Genus *Hydrobiosella* Tillyard

Hydrobiosella Tillyard, 1924: 288; Neboiss 1977: 45.

Type species
Hydrobiosella stenocerca Tillyard, 1924 by monotypy.

The genus is well represented in Tasmania with 15 species, placed in three species groups.

corinna group — four species

Characterised by very slender male genitalia, small but distinct superior appendages at the base of segment X; sternite and tergite IX both strongly sclerotised and fused; inferior appendages slender, harpago with small group of short dark setae on the inner surface, phallus elongate with sclerotised inner spines near apex.

Species included
Corinna Neboiss; *orba* Neboiss; *anasina* Neboiss and *cerula* Neboiss.

tasmanica group — ten species

Male genitalia somewhat stouter than in *corinna* group; superior appendages absent; sternite and tergite IX both strongly sclerotised and fused; inferior appendages, slender, harpago with small group of short, dark setae on the inner surface and a single curved bristle at the apex; phallus elongate with pair of sclerotised lateral bars and apical pair of downturned stout spines.

Species included
Tasmanica Mosely; *anatolica* sp. n.; *armata* Jacquemart; *cognata* Kimmins; *sagitta* Neboiss; *propinqua* sp. n.; *disrupta* sp. n.; *otaria* sp.a.; *scalaris* sp. n.; *tahunense* sp. n.

waddama group — one species

Male genitalia rather more robust than in the other two groups; superior appendages absent; segment IX with tergite membranous, only sternite sclerotised, rather elongate; inferior appendages robust; phallus with pair of long curved processes.

Species included
Waddama Mosely.

corinna group

Hydrobiosella corinna Neboiss
Figs 8A, 8B, 9A

Hydrobiosella corinna Neboiss, 1977: 47.

Holotype
♂ Tasmania, Corinna (small creek in forest), 5 Nov. 1972 (NMV).

Additional material examined
Tasmania, ♂ (numerous) Franklin River-Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A.Neboiss (male genitalia prep. PT-2209 illustrated) NMV.

Diagnosis
Male genitalia (fig. 8A, B) superior appendages present, short, somewhat pointed apically; segment X in dorsal view rather robust elongate, somewhat triangular apically. Phallus membranous with one sclerotised spine about midway, and a pair of V-shaped sclerites near distal end.

Distribution
Tasmania, NW and northern SW provinces. Tasmanian endemic.

Hydrobiosella orba Neboiss
Figs 8C, 8D, 9B

Hydrobiosella orba Neboiss, 1977: 47.

Holotype
♂ Tasmania, Wedge River, 17 Feb. 1971 (NMV).

Additional localities
Tasmania, 11♂ Gordon River, 1 km above First Split, 11 Jan. 1977, A. Neboiss; 7♂ Gordon River, 500 m below Second Split, 12 Jan. 1977, A. Neboiss (male genitalia prep. PT-2194 illustrated); 1♂ Ropeway Creek, 400 m below Smith and Gordon River junction, 2 Feb. 1977, D. Coleman; 1♂ stream, 300 m W of Teds Beach turnoff, 14 Jan. 1999, J. Jackson; 1♂ Lake Oberon, Western Arthur Ranges, top of plain, 9 Mar. 1999, J. Jackson. (All specimens in NMV.)

Diagnosis
Male genitalia (fig. 8C, D) superior appendages somewhat smaller than in *corinna*; segment X shorter, in dorsal view almost triangular. Phallus membranous with two pairs of strongly sclerotised V-shaped sclerites, one pair about midway the other near distal end.

Distribution
Tasmania, SW province. Tasmanian endemic.

Hyrobiosella anasina Neboiss
Figs 8E, 8F, 9C

Hydrobiosella anasina Neboiss 1977: 48.

Holotype
♂ Tasmania, Duck River, 6 km SW of Roger River, 29 Nov. 1974 (NMV).

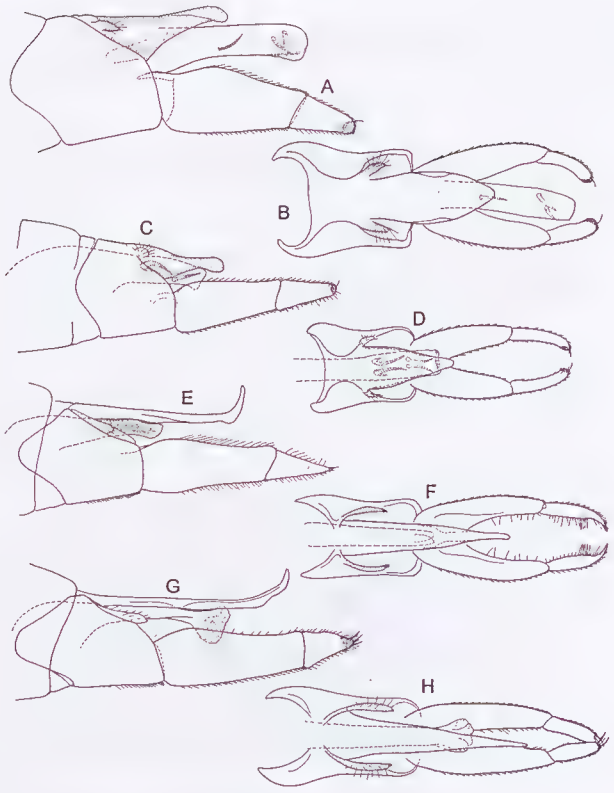

FIG. 8 — Hydrobiosella *spp., male genitalia. (A, B)* H. corinna*: (A) lateral; (B) dorsal. (C, D)* H. orba*: (C) lateral; (D) dorsal. (E, F)* H. anasina*: (E) lateral; (F) dorsal. (G, H)* H. cerula*: (G) lateral; (H) dorsal.*

Additional localities
Tasmania, 22♂ Gordon River, 1 km above First Split, 11 Jan. 1977, A. Neboiss (male genitalia prep. PT-2261 illustrated); 4♂ Lake Tahune, Frenchmans Cap area, 29 Jan. 1988, J. Jackson. (NMV).

Diagnosis
Male genitalia (fig. 8E, F) superior appendages present; segment X long, slender, tapering distally, extends almost to the base of harpago, apex laterally somewhat compressed and more or less abruptly turned upward. Inferior appendages long, harpago less than half the length of coxite, in lateral view somewhat triangular, terminates with mesally directed acute point. Phallus membranous without internal sclerotised spines, several rows of fine spicules laterally at distal end.

Distribution
Tasmania — NW, C and northern SW provinces. Tasmanian endemic.

Hydrobiosella cerula Neboiss
Figs 8G, 8H, 9D

Hydrobiosella cerula Neboiss, 1977: 48.

Holotype
♂ Tasmania, Lake Pedder (original shores before flooding), 10 Mar. 1972 (NMV).

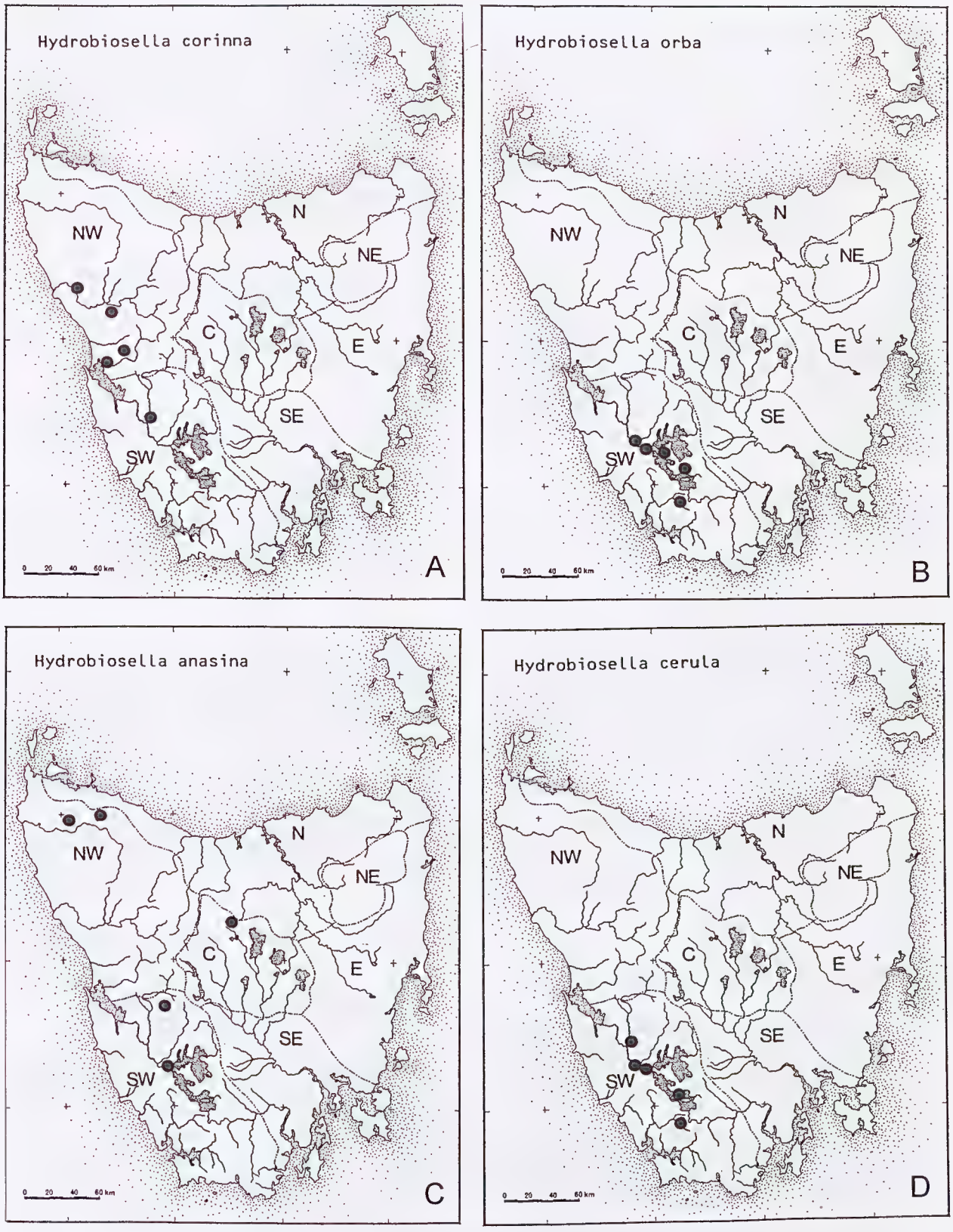

FIG. 9 — Distribution maps for Hydrobiosella *spp.: (A)* H. corinna*; (B)* H. orba*; (C)* H. anasina*; (D)* H. cerula.

Additional localities
Tasmania, 4♂ Ropeway Creek, 400 m below Gordon and Smith River junction, 2 Feb. 1977, D.Coleman (male genitalia prep. PT-2262 illustrated); 3♂ Franklin River-Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss; 2♂ Gordon River, 2 km below Serpentine River junction, 12 Jan. 1977, A. Neboiss; 1♂ Olga Camp near Gordon and Smith River junction, 2 Feb. 1976, Howard and Suter; 1♂ Lake Oberon, Western Arthur Ranges, top of plain, 9 Mar. 1999, J. Jackson. All specimens in NMV.

Diagnosis
Male genitalia (fig. 8G, H) similar to that in *H. anasina*, but differs by having the apex of segment X only gradually turned upwards; superior appendages present; inferior appendages long, harpago short, in lateral view sub-triangular, apex directed mesally and terminates bluntly with three or four strong claw-like spines. Phallus proportionally longer than in *anasina*, apex widened and covered with small irregularly dispersed spicules.

Distribution
Tasmania, SW province. Tasmanian endemic.

tasmanica group

This group appears to be a complex of a number of closely related species, which differs from each other only by details of segments IX and X in male genitalia. Based on present interpretation, ten species are recognised, each with rather restricted distribution as shown on the maps in figure 13A–D. It should also be noted that all species of this group have a distinct curved bristle at the distal end of harpago.

Hydrobiosella tasmanica Mosely
Figs 10A, 10B, 13A

Hydrobiosella tasmanica Mosely *in* Mosely & Kimmins, 1953: 390; Neboiss 1977: 49.

Holotype
♂ Tasmania, (without definite locality or date) (BMNH).

In addition to the previously recorded localities further material has been collected which confirms the presence of this species in southern and southwestern Tasmania.

Additional localities
Tasmania. 2♂ Old River Collins River junction, 10 Feb. 1988, A. Neboiss (male genitalia prep. PT-2263 illustrated); 8♂ d'Entrecasteaux River, South Cape road bridge, 14 Feb. 1988, A.Neboiss; 12♂ Tomalah Creek, mid site, 9 Mar. 1988, S. Chilcott; 4♂ Gordon River, 2 km below Serpentine River junction, 12 Jan. 1977, A. Neboiss; ♂ (numerous) Condominion Creek, at Scotts Peak Road, 9 Feb. 1988, A. Neboiss and J. Jackson; 1♂ same loc., 26 Jan. 1988, J. Jackson; 3♂ same loc. 2 Dec. 1998, J. Jackson; 1♂ Mulcahy Bay, Alec Rivulet, 12–15 Jan. 1988, J. Jackson. All specimens in NMV.

Diagnosis
Dark brown to brown species, forewings with irregular mottling. Male genitalia (fig. 10A, B) with distinctly shaped tergite IX, the lower angle of which is extended into long upcurved digital process. Segment X in dorsal view with small lateral flanges at about middle of the segment. Phallus slender, with a pair of strong , ventrally directed peg-like teeth, and a pair of small spines at distal end of dorsal membranous part.

Distribution
SE and SW provinces (fig. 13A). Tasmanian endemic.

Hydrobiosella armata Jacquemart
Figs 10C, 10D, 13B

Hydrobiosella armata Jacquemart, 1965: 34; Neboiss 1977: 8C.

Holotype
♂ Tasmania, Mt Wellington, 20 Nov. 1922 (IRScNB).

Additional localities
Tasmania. 2♂ Truggara Creek (Huon tributary) mid site, 9 Mar. 1988, S. Chilcott; 3♂ Tomalah Creek (Huon tributary) mid site, 9 Mar. 1988, S. Chilcott; 2♂ d'Entrecasteaux passage, exit cave (1.7 km into dark zone), Jan. 1993, A. Clarke (male genitalia prep. PT-2048 illustrated).

Diagnosis
Although very close to *H. tasmanica*, *H. armata* is distinguished by the shorter and rounded tergite IX, and distinctly formed segment X as shown in figure 10C, D. Phallus without small terminal spines. *H. armata* is restricted mainly to the SE province, with only a few records from the SW province at Truggara and Tomalah Creeks where it occurs along with *H. tasmanica*. From these two localities there are several specimens that may be hybrids. The differences in the shape of tergite IX and segment X are still regarded as sufficiently distinct to distinguish these two species.

Distribution
SE and SW provinces (fig. 13B). Tasmanian endemic.

Hydrobiosella cognata Kimmins
Figs 10G, 13C

Hydrobiosella cognata Kimmins *in* Mosely & Kimmins, 1953: 392; Jacquemart 1965: 32; Neboiss 1974: 15; Neboiss 1977: 50.
Hydrobiosella spinosa Jacquemart 1965: 33.

Holotype
♂ Tasmania, Lake St Clair, Feb. 1941 (BMNH).

Distribution records as given by Neboiss (1977) with only one additional locality: 1♂ Hellyer River Gorge, 12 Dec. 1974, A. Neboiss (male genitalia prep. PT-577 illustrated) NMV.

Diagnosis
Male genitalia (fig. 10G) tergite IX rounded dorsally, the digital upcurved process robust, apex more or less bluntly rounded; segment X in dorsal view only slightly wider at

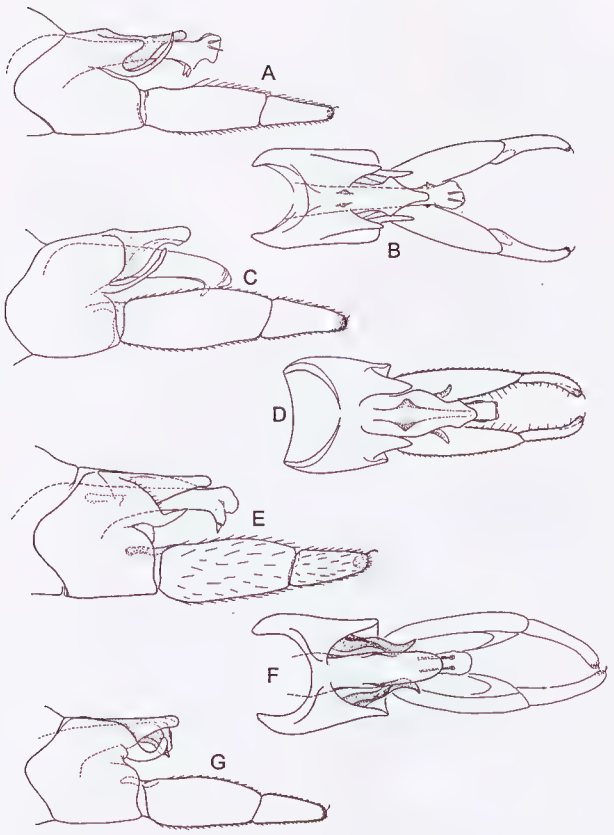

FIG. 10 — Hydrobiosella *spp., male genitalia. (A, B)* H. tasmanica*: (A) lateral; (B) dorsal. (C, D)* H. armata*: (C) lateral; (D) dorsal; (E, F)* H. tahunense*: (E) lateral; (F) dorsal. (G)* H. cognata*, lateral.*

base, with a pair of small triangular dorsal lobes. Phallus similar to that in *H. tasmanica*, but proportionally shorter; pair of downturned peg-like teeth present, the small terminal spines absent.

Distribution
N, C and NW provinces (fig. 13C). Tasmanian endemic.

Hydrobiosella tahunense sp. n.
Figs 10E, 10F, 13C

Type material
Holotype ♂ Tasmania, Lake Tahune, Frenchmans Cap area, 29 Jan. 1988, J. Jackson; Paratypes 3♂ collected with holotype (male genitalia prep. PT-1702 illustrated); 1♂ Nelson River below Lyell Highway bridge, 3 Nov. 1988, J. Jackson; 1♂ Cardigan River above Lyell Highway bridge, 16 Feb. 1999, J. Jackson. All specimens in NMV.

Diagnosis
Greyish-brown to brown species; irregular dark spots along costal margin. Length of forewing ♂ 6.6–7.3 mm (Nelson River specimen 8.3 mm). Male genitalia (fig. 10E, F) similar to that of *H. tasmanica* but tergite IX dorsal margin gradually curved, lower distal angle produced into pointed, slightly upcurved digital process; segment X almost parallel-sided, widest at basal third with small triangular lobes; phallus straight with pair of strong downward directed peg-like teeth; upper membranous section without internal spines.

Etymology
Named after the type locality — Lake Tahune.

Distribution
NE and SW provinces (fig. 13C). Tasmanian endemic.

Hydrobiosella anatolica sp. n.
Figs 11A–11C, 13B

Type material
Holotype ♂ Tasmania, Fortescue Bay, Mill Creek 43°08'S, 147°58'E, 28 Feb. 2001, R. Walker. Paratypes 4♂ 1♀ collected with holotype (male genitalia preps PT-2251, female PT-2252 illustrated); 1♂ Anglers Creek, Little Swanport, 13 Oct. 1977, D. Coleman. All specimens in NMV.

Diagnosis
Greyish-brown species, forewings with irregular mottling along costal margin. Length of forewing ♂ 7.2–7.7 mm; ♀ 7.9 mm. Male genitalia (fig. 11A, B) with division between tergite and sternite of segment IX short; distal part of tergite squarish, lower distal angle with slightly upcurved digital process; segment X in dorsal view with lateral lobes near apex and a pair of triangular lobes near base which are species specific. Phallus with strong downward directed peg-like teeth, membranous part without terminal spines. Female (fig. 11C) with one pair of apodemes in segments VIII and IX.

Etymology
Anatole (Gr.) — east, in reference to the distribution of the species.

Distribution
E and SE provinces — Tasmanian east coast (fig. 13B). Tasmanian endemic.

Hydrobiosella sagitta Neboiss
Figs 11D, 11E, 13B

Hydrobiosella sagitta Neboiss, 1977: 51.

Holotype
♂ Tasmania, St Columba Falls nr Pyengana, 21 Feb. 1971 (NMV).

Only one additional specimen has been collected since the species was described in 1977 and it also came from the vicinity of the type locality. 1♂ St Columba Falls, Pyengana, 10 Mar. 1982, D. Cartwright (NMV).

Diagnosis
Distictively formed tergite IX, segment X and phallus distinguishes it from all other species in Tasmania.

Distribution
NE province, known only from type locality (fig. 13B). Tasmanian endemic.

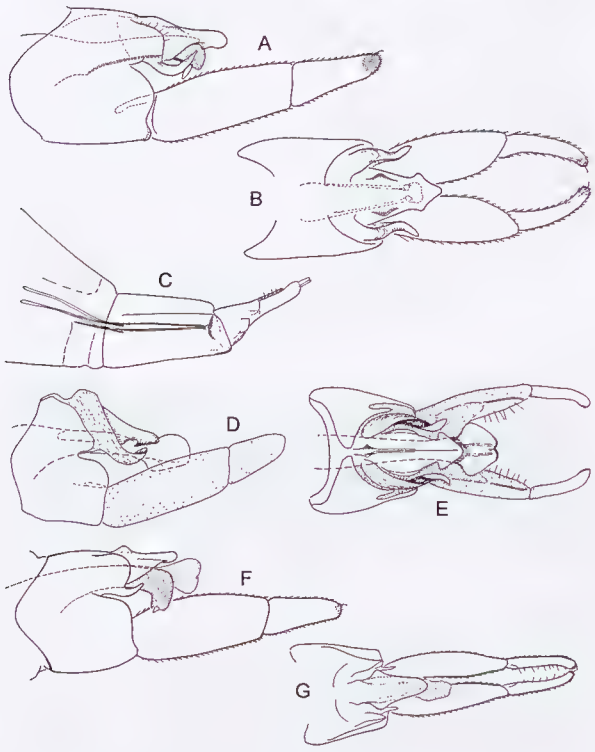

FIG. 11 — Hydrobiosella *spp. (A–C)* H. anatolica*: (A) male genitalia lateral; (B) male genitalia dorsal; (C) female genitalia, lateral. (D, E)* H. sagitta *male genitalia: (D) lateral; (E) dorsal.(F, G)* H. disrupta *male genitalia: (F) lateral; (G) dorsal.*

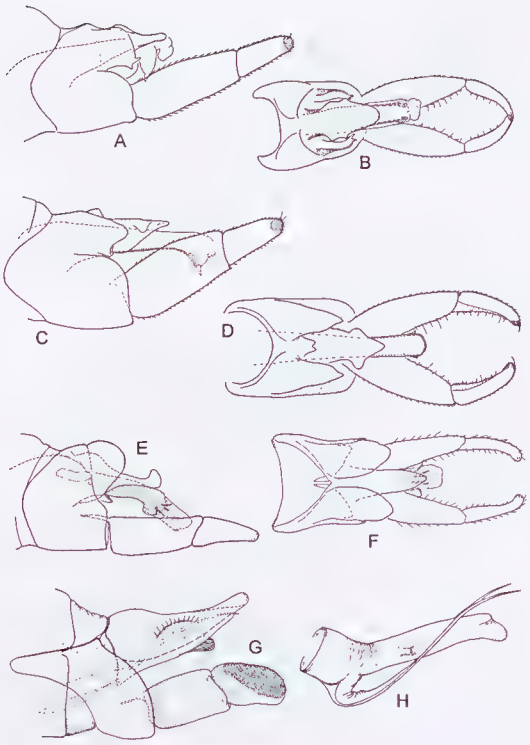

FIG. 12 — Hydrobiosella *spp., male genitalia. (A, B)* H. propinqua*: (A) lateral; (B) dorsal. (C, D)* H. scalaris*: (C) lateral; (D) dorsal. (E, F)* H. otaria*: (E) lateral; (F) dorsal. (G, H)* H. waddama: *(G) lateral; (H) phallic structure.*

Hydrobiosella disrupta sp. n.
Figs 11F, 11G, 13D

Type material
Holotype ♂ Tasmania, Gordon River, 500 m below Second Split, 12 Jan. 1977, A. Neboiss. Paratypes 4♂ collected with holotype (male genitalia prep. PT-575 illustrated); l♂ Gordon River, 1 km above First Split, 11 Jan. 1977, A. Neboiss (NMV).

Diagnosis
Yellowish-brown species with slight mottling on forewings. Length of forewing — ♂ 7.7–8.3 mm. In basic form, the male genitalia (fig. 11F, G) resemble those of *H. tasmanica*, but are distinguished by having tergite IX shorter and more rounded, ventro-apical digital process rather short, slightly upcurved; segment X short, similar to that of *H. propinqua*, in dorsal view widest near base formed by elevated triangular lateral flanges. Phallus with pair of peg-like teeth directed downward at apex.

Etymology
Disruptus (L) — broken up, in reference to type of terrain at the type locality.

Distribution
SW province — known only from the type locality (fig. 13D). Tasmanian endemic.

Hydrobiosella propinqua sp. n.
Figs 12A, 12B, 13D

Type material
Holotype ♂ Tasmania, Smith River at Gordon River junction, 15 Jan. 1977, A. Neboiss. Paratypes 3♂ collected with holotype; l♂ Smith River, 100 m from Gordon River junction, 7 Feb. 1977, D. Coleman (male genitalia prep. PT-2193 illustrated); 8♂ Franklin River, Roaring Creek Junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss. All specimens in NMV.

Other material examined
Tasmania, 3♂ Sir John Falls, Cataract Creek, Gordon River tributary, 9 Jan. 1977, A. Neboiss, NMV.

Diagnosis
Yellowish-brown to light brown species, sometimes with mottling on forewings. Length of forewing ♂ 7.8–8.6 mm. Similar to *H. tasmanica*, but distinguished by the squarish, distally produced tergite IX and two small digitiform processes at the apico-ventral angle; segment X rather short, in dorsal view it has two pairs of lateral flanges (fig. 12A).

Etymology
Prope (L) — near, in reference to the similarity of other *Hydrobiosella* species.

Distribution
SW province (fig. 13D). Tasmanian endemic.

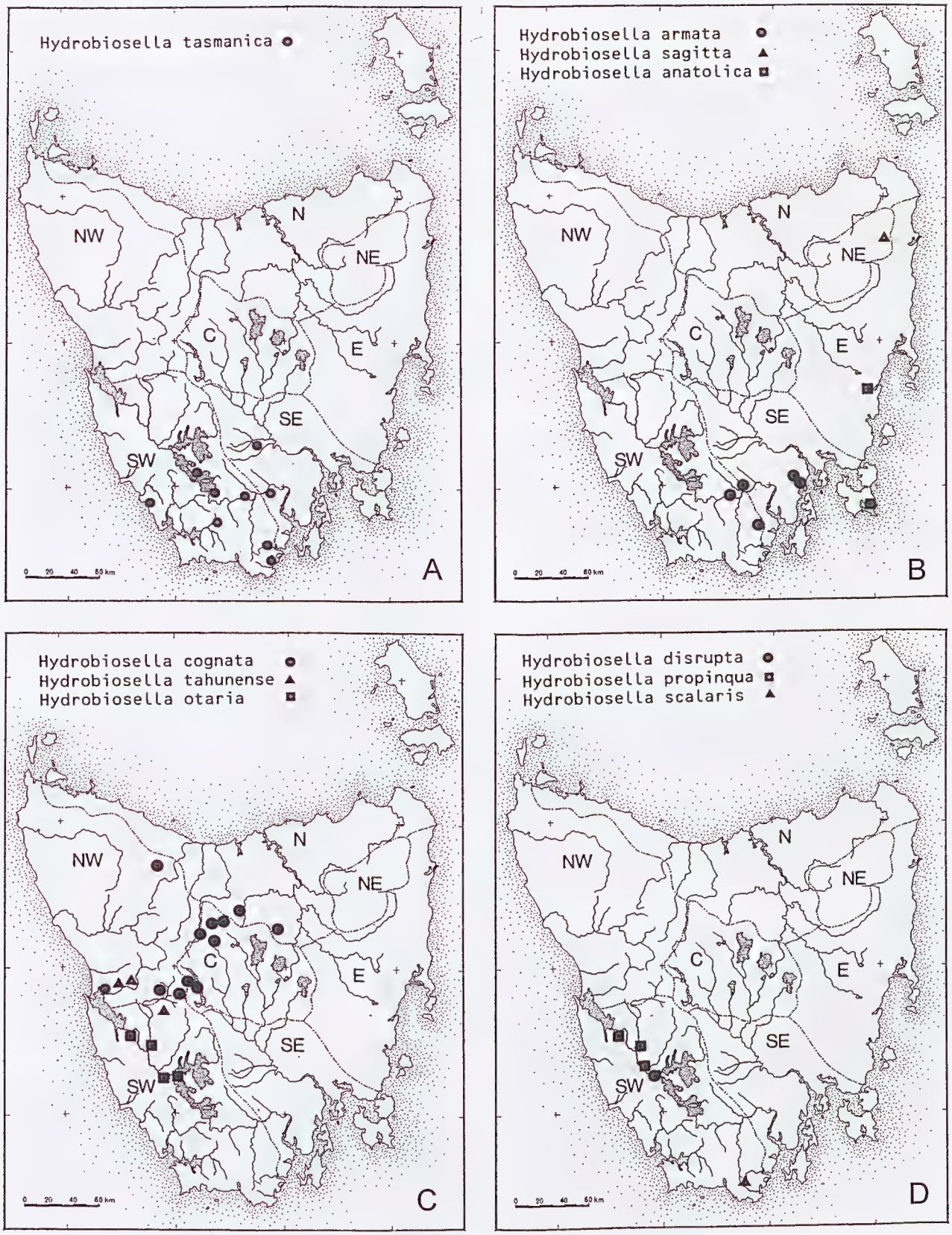

FIG. 13 — Distribution maps for Hydrobiosella *spp.: (A)* H. tasmanica*; (B)* H. armata, H. anatolica *and* H. sagitta*; (C)* H. cognata, H. tahunense *and* H. otaria*; (D)* H. disrupta, H. propinqua *and* H. scalaris.

Hydrobiosella scalaris sp. n.
Figs 12C, 12D, 13D

Type material
Holotype ♂ Tasmania, d'Entrecasteaux River source, below Mt LaPerouse, 43°30'S, 146°44'E, alt. 840 m (sweep net), 16 Feb. 1988, A. Neboiss (male genitalia prep. PT-2202 illustrated), NMV.

Diagnosis
Pale yellowish-brown species, without obvious mottling. Length of forewing ♂ 8.2 mm. Male genitalia of similar plan to that in *H. tasmanica*, but distinguished by the total absence of apico-ventral process on tergite IX, upper margin developed into a rounded lobe; segment X with a pair of somewhat rounded lateral lobes near distal end and an elevated dorsal bipointed projection at base. Phallus with pair of stout peg-like teeth at apex.

Etymology
Scalaris (L) — of a ladder, in reference to the elevation of the type locality.

Distribution
SW province, known only from the type locality (fig. 13D). Tasmanian endemic.

Hydrobiosella otaria sp. n.
Figs 12E, 12F, 13C

Type material
Holotype ♂ Tasmania, Sir John Falls, Cataract Creek, Gordon River tributary, 42°34'S, 145°41'E, 9 Jan. 1977 A. Neboiss. Paratypes 8♂ collected with holotype (male genitalia prep. PT-567 illustrated); 5♂ Gordon River, 500 m below Second Split, 12 Jan. 1977, A. Neboiss; 3♂ Gordon River, 1 km above First Split, 11 Jan, 1977, A. Neboiss; 2♂ Franklin River-Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss; 11♂ Strathgordon, Jan. 1977, J. Sedlacek. All specimens in NMV.

Diagnosis
Greyish-brown to brown species, forewing with indistinct mottling. Length of forewing ♂ 6.3–6.9 mm. Male genitalia (fig. 12E, F) segment IX short, tergite distally developed into large ear-like lobe, lower mesal angle somewhat pointed; segment X in dorsal view elongate triangular, apex raised to a short vertical ridge. Phallus slender, slightly curved downward, one pair of V-shaped chitinous spines near apex.

Etymology
Otos (Gr) — ear, in reference to the shape of tergite IX.

Distribution
SW province (fig. 13C). Tasmanian endemic.

waddama group

Hydrobiosella waddama Mosely
Fig. 12G, H

Hydrobiosella waddama Mosely *in* Mosely & Kimmins, 1953: 393; Neboiss 1977: 52.

Holotope
♂ Tasmania, Waddamana, River Ouse (no date) (BMNH).

This well-known and common species is widely distributed throughout most of Tasmania, but there are no records from the E province. This is the only species of the group in Tasmania. All others are in Victoria, New South Wales and Queensland. The main distinguishing characteristics are the more robust inferior appendages, rounded harpago with a large patch of short, black setae and phallus with a pair of long processes arising from its base (fig. 12H).

Additional localities
Tasmania – 1♂ Denison River, 200 m below Maxwell River junction, 10 Jan. 1977, A. Neboiss; 1♂ 1♀ Port Arthur, Jan. 1977, J. Sedlacek; 1♂ Gordon River, 200 m above Olga River junction, (no date), D. Coleman; 9♂ Franklin River above Lyell Highway bridge, 16 Feb. 1999, J. Jackson; 1♀ Scotts Peak Dam, Serpentine impoundment, 23 Mar. 1985, P. Greenslade; 6♂ Agnes Creek, Fortescue Bay, 28 Feb. 2001, R. Walker; ♂ ♀ (numerous 50+) Pinetree Rivulet, Lake Highway near Breona, 9. Feb. 2001, R. Walker (male genitalia prep. PT-2258 illustrated); 1♂ 1♀ Doctors Creek at Lake Highway nr Breona, 9 Feb. 2001, R. Walker. All specimens in NMV.

Distribution
Tasmania, widespread, common. Other states: Victoria, New South Wales.

FAMILY ECNOMIDAE

The family Ecnomidae in Tasmania is represented by three genera — *Ecnomus* McLachlan, *Ecnomina* Kimmins and *Daternomina*, a new genus introduced in this paper. This genus has been erected to include some species previously placed in *Ecnomina*, in which the hind wing anal veins are distinctly bent and the female sternite VIII is divided into two lobes. Two new species are also described in this genus.

Genus *Ecnomus* McLachlan

Ecnomus McLachlan, 1864: 30; Neboiss 1977: 54; Cartwright 1990: 21.

Type species
Philopotamus tenellus Rambur, 1842 by monotypy.

The genus in Tasmania is represented by four species — *E. tillyardi* Mosely, *E. russellius* Neboiss, *E. turgidus* Neboiss and *E. cygnitus* Neboiss. This latter name replaces *E. continentalis* Ulmer. The identification of this species was based on illustration in Mosely & Kimmins (1953: fig. 261), which was prepared from a South Australian specimen, and as such was wrongly identified. The true identity of *E. continentalis* was established when the lectotype was re-examined and figured by Neboiss (1982). To allow positive recognition of the Tasmanian species the figure of *E. continentalis* is included (fig. 14G).

Ecnomus cygnitus Neboiss
Figs 14A–C, 15C, 15D, 18A

Ecnomus cygnitus Neboiss, 1982: 288; Cartwright 1990: 16.

Holotype
♂ Victoria, Swan Lake, 30 km NW of Portland, 27 Feb. 1976 (NMV).

Tasmanian records
5♂ 9♀ West Bay River, Margate, 6 Jan. 1977, A. Neboiss and P. Allbrook (male genitalia prep. PT-1069 illustrated); 1♂ Carlton River, Carlton, 26 Dec. 1975, M. Davies; 1♂ South Esk River, Evandale, 1 Mar. 1967, A. Neboiss (recorded as *E. continentalis* by Neboiss 1977); l♂ Apsley River, 5 km NW of Bicheno, 20 Dec. 1988, J. Jackson; l♂ Lake Pedder, Site 'J' Dec. 1977, P.S. Lake; 6♂ 3♀ Lake Fiddler, Lower Gordon River, 13 Dec. 1977, D. Coleman; l♂ Scotts Peak Dam, Serpentine impoundment, 23 Apr. 1985, Greenslade and Rounsevell; 1♂ 1♀ Arve River, 3 Feb. 1983, J. Cardale; 1♂ 2♀ Lake Pedder, shore N of Forest Creek, 12 Feb. 1999, J. Jackson; 17♂ 5♀ Maria Creek near Lake Pedder, 10 Feb. 1999, J. Jackson; 1♂ Pebbly Creek, 50 m upstream of Lake Pedder, 10 Feb. 1999, J. Jackson; 2♂ stream South of Timber Creek, 10 Feb. 1999, J. Jackson; 1♂ Lake Pedder, Frankland shore, 10 Feb. 1999, J. Jackson; 1♂ Doctors Creek at Lake Highway near Breona, 9 Feb. 2001, R. Walker. All specimens in NMV.

Male genitalia (fig. 14A–C) with superior appendages in lateral view robust, broadest in median section; inferior appendages in ventral view with subapical mesal projection at about the middle, separated widely from apical angle.

Female genitalia (fig. 15C, D) with rounded pocket near meso-basal angle; ventral plate slightly concave.

Distribution
Tasmania, scattered locality records from E, C and SW provinces. Other states: Victoria, South Australia, New South Wales, Queensland.

Ecnomus tillyardi Mosely
Figs 14D, 14E, 15E, 15F

Ecnomus tillyardi Mosely *in* Mosely & Kimmins, 1953: 378; Neboiss 1977: 55; Cartwright 1990: 14.

Holotype
♂ Tasmania (without definite locality or date) (BMNH).

Distribution
This is the most common and widespread of *Ecnomus* species in Tasmania. Large numbers are collected throughout the Southwest National Park with collecting dates ranging from December through to March. Other states: South Australia, Victoria, New South Wales.

Ecnomus turgidus Neboiss
Fig. 14F

Ecnomus trugidus Neboiss, 1982: 289; Cartwright 1990: 8; Jackson 2000: 59.

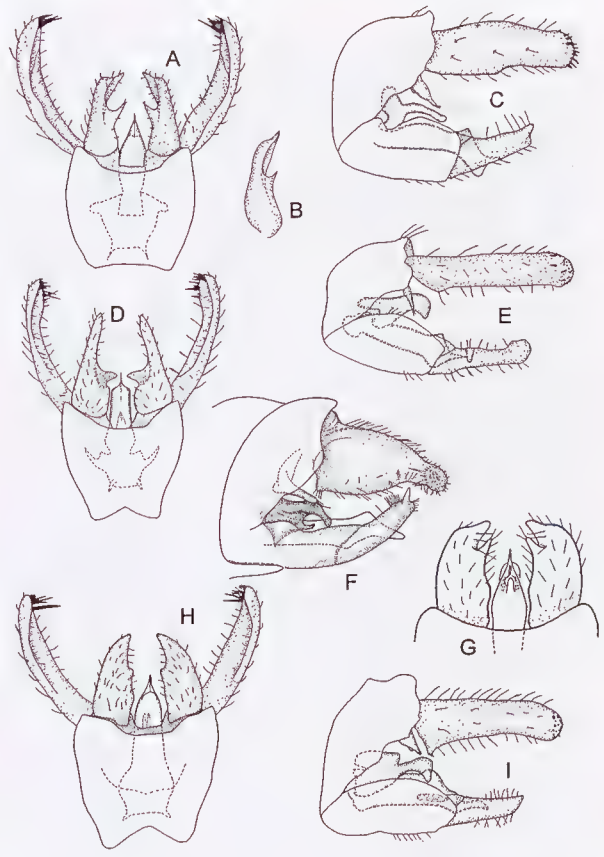

FIG. 14—Ecnomus *spp., male genitalia. (A–C)* E. cygnitus*: (A) ventral; (B) inferior appendage – variety; (C) lateral. (D, E)* E. tillyardi*: (D) ventral; (E) lateral. (F)* E. turgidus*: lateral (Tasmanian specimen CT-274). (G)* E. continentalis*, ventral. (H, I)* E. russellius*: (H) ventral; (I) lateral.*

Tasmanian records
1♂ Maria Creek nr Lake Pedder, 10 Feb. 1999, J. Jackson and B. Mawbey (NMV) (male genitalia prep. CT-274 by Cartwright illustrated).

Male genitalia (fig. 14F) with superior appendages in lateral view broad-based, tapering distally, slightly constricted before rounded apex which bears a group of inflected spines on inner surface; a rounded lobe present on ventral margin near base; inferior appendages in lateral view slender, apically with distinct, dorsally directed digital projection; paramere in lateral view differs from the typical form by second, ventrally situated lobe. At present this character state is not regarded as sufficient for species separation, and more material is required to clarify the variability of the paramere.

Distribution
Tasmania — SW province. Other states: Western Australia, South Australia, Victoria, Queensland.

Ecnomus russellius Neboiss
Figs 14H–15B

Ecnomus russellius Neboiss, 1977: 56; Cartwright 1990: 22.

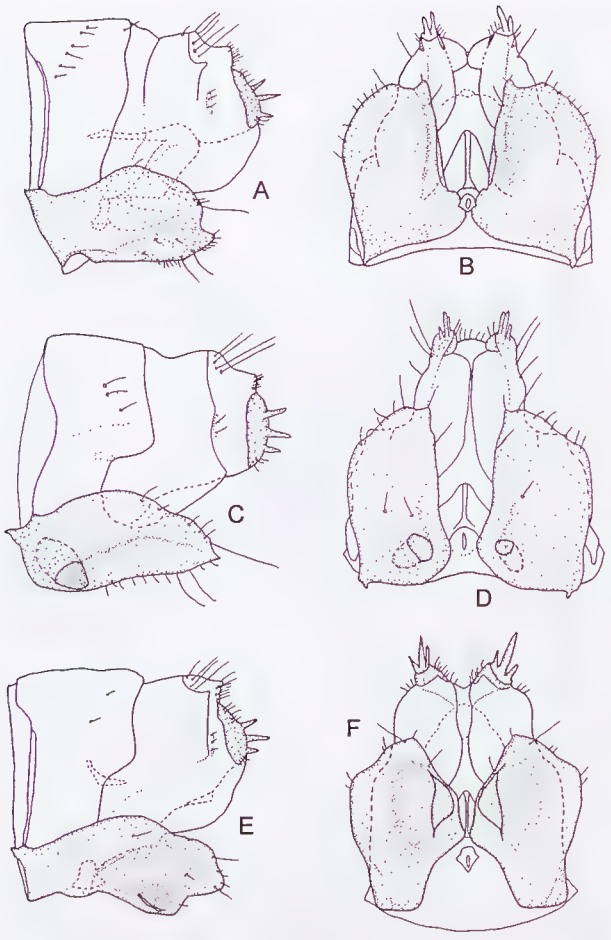

FIG. 15 — Ecnomus *spp., female genitalia. (A, B)* E. russellius*: (A) lateral; (B) ventral. (C, D)* E. cygnitus*: (C) lateral; (D) ventral. (E, F)* E. tillyardi*: (E) lateral; (F) ventral.*

Holotype
♂Tasmania, Russell Falls, 20 Feb. 1967 (NMV).

In addition to the localities recorded since in the *Ecnomus* revision by Cartwright (1990), 3♂, Doctors Creek at Lake Highway near Breona, 9 Feb. 2001, R. Walker (NMV).

Distribution
Tasmania, C and E provinces. Other states: Victoria, New South Wales, SE Queensland.

Genus *Ecnomina* Kimmins

Ecnomina Kimmins *in* Mosely & Kimmins, 1953: 380; Neboiss 1977: 57.

Type species
Ecnomina spinosa Kimmins by original designation.

The genus *Ecnomina* s.str. is characterised by absence of nygma in forewing fork 2; comparatively long fork 3, either reaching or ending close to cross-vein m at a distance not exceeding the length of cross-vein. Hind wing comparatively narrow, anal veins running almost straight from base of the wing to margin. In female the abdominal sternite VIII extends into more or less narrow, elongate mesal process. The larvae of 'sentosa' group from SW Australia as identified by Neboiss (1982), to which three Tasmanian species also belong, are considered as typical of the genus *Ecnomina* and described by Dean & Bunn (1989). It is characterised by subovate head capsule; medium length, robust ligula; all thoracic nota sclerotised; mesonotum and metanotum with median ecdysial line, and also each with narrow dark line extending obliquely back from near antero-lateral corner.

Three Tasmanian species – *batyle* Neboiss, *legula* Neboiss, and *vega* Neboiss – are referred to this genus.

Ecnomina legula Neboiss
Fig. 16A, B

Ecnomina legula Neboiss 1977: 58.

Holotype
♂ Tasmania, Huon River Crossing, Port Davey Track, 9 Feb. 1965 (NMV).

Additional Tasmanian material examined
Numerous ♂ and ♀ Maria Creek near Lake Pedder, 10 Feb. 1999, J. Jackson; 4<♂ 6♀ d'Entrecasteaux River at South Cape road bridge, 14 Feb. 1988, A. Neboiss and K. Walker; 20♂ ♀ Mulcahy Bay area, Alec Rivulet tributary, 12–15 Jan. 1988, J. Jackson. All specimens in NMV.

Distribution
Tasmania, scattered localities, common where present. Tasmanian endemic.

Ecnomina batyle Neboiss

Ecnomina batyle Neboiss, 1977: 59.

Holotype
♂Tasmania, Wilmot River, 10 km S of Forth, 13 Dec. 1974 (NMV).

Additional localities
5♂ 5♀ West Bay River, Margate, 6 Jan. 1977, A. Neboiss (NMV).

Distribution
Tasmania, N, C and SE provinces, scattered localities only, rare. Tasmanian endemic.

Ecnomina vega Neboiss

Ecnomina vega Neboiss, 1977: 58.

Holotype
♂ Tasmania, Macquarie River, 8 km W of Campbell Town, 9 Nov. 1972 (NMV).

Distribution
Tasmania E province, known from type locality only. No additional specimens available. Tasmanian endemic.

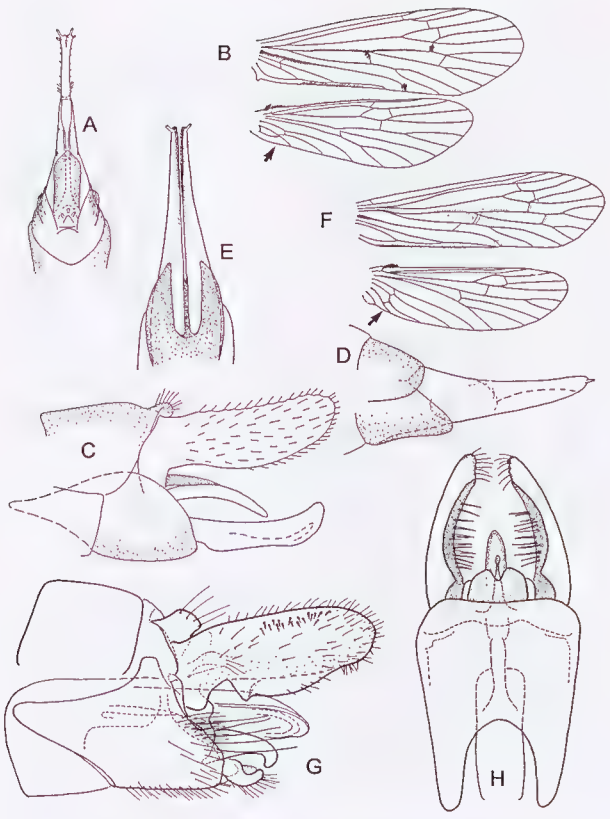

FIG. 16 — (A, B) Ecnomina legula *Neboiss: (A) female genitalia ventral; (B) male wing venation. (C–F)* Daternomina irrorata *(Kimmins): (C) male genitalia lateral; (D) female genitalia lateral; (E) female genitalia ventral; (F) female, wing venation. (G, H)* Daternomina quasitrulla *sp. n., male genitalia: (F) lateral; (H) ventral.*

Genus *Daternomina* gen. nov.

Type species

Ecnomina irrorata Kimmins, 1953, by present designation.

Neboiss (1982) recognised two distinct species groups within the genus *Ecnomina* s.lat. when describing the SW Australian fauna. At that time it was also realised that this division is applicable to all *Ecnomina* species in Australia. Support for this grouping from larval characters was discussed by Cartwright & Dean (1982) and by Dean & Bunn (1989).

The *'sentosa'* group, to which the type species *Ecnomina spinosa* Kimmins from New South Wales belongs, is characterised by forewing fork 2 without nygma, comparatively long fork 3 with very short footstalk, about as long or shorter than cross vein m; rather narrow hind wings with anal veins almost straight. The female abdomen with sternite VIII developed into an elongate meso-ventral lobe (fig. 16A). This group represents *Ecnomina* s.str. The *'scindens'* group, including *Ecnomina irrorata* Kimmins, is diagnosed by forewing fork 2 with nygma present, fork 3 with footstalk longer than cross-vein m; hind wing somewhat broader with distinctly curved anal veins. The female abdomen with sternite VIII formed by lateral lobes widely separated meso-ventrally (fig. 16E). This group is here removed to a new genus, *Daternomina.*

Description

Maxillary palps slender, segment 5 about as long as the first four together; forewing R1 forked; fork 1 absent; fork 2 sessile, nygma present; fork 3 comparatively short, footstalk slightly longer than the cross-vein m; hind wing forks 2, 3 and 5 present; anal veins distinctly curved at the level of connecting cross veins. Male abdominal sternite V antero-laterally with a small ear-shaped lobe, connected internally with a small round gland (as described by Ward & Schefter (2000).

Larvae recognised as the *'scindens'* group were characterised by Dean & Bunn (1989) as follows: head capsule broadest near posterior margin. Ligula long and needle-like. All thoracic nota sclerotised. Meso- and metanotum with sclerotisations reduced, resulting in broad membranous area along midline. Dark lines on mesonotum branched, situated more dorsally than in species of the *'sentosa'* group [= *Ecnomina* s. str.].

This genus includes *D. irrorata*, and the southwestern Australian species *scindens* (Neboiss), *trulla* (Neboiss) and *merga* (Neboiss); the SE Queensland *krokale* (Neboiss), *chorisis* (Neboiss) and *thinotes* (Neboiss); and two species newly described here, *quasitrulla* and *jacksonae* from Tasmania.

Etymology

Daterios — Gr. dividing, combined with part of generic name *Ecnomina*, in reference to the deeply divided sternite VIII in females.

Daternomina irrorata (Kimmins) comb. nov. Fig. 16C–E

Ecnomina irrorata Kimmins *in* Mosely & Kimmins, 1953: 385; Neboiss 1977: 57.

Holotype

♂ Tasmania, Deloraine, 26–27 Dec. 1884, McLachlan Coll. (BMNH).

Additional localities

Tasmania — ♂ ♀ Mulcahy Bay area, Alec Rivulet tributary, 12–15 Jan. 1988, J. Jackson; 1♂ Twin Creeks, Scotts Peak Dam road, 9 Feb. 1988, J. Jackson; 1♂ Old River and Collins River junction 10 Feb. 1988, J. Jackson; 1♀ Sandfly Creek, Scotts Peak road, 9. Feb. 1988, K. Walker and J. Jackson; 1♀ Condominion Creek, Scotts Peak Dam road, 9 Feb. 1988, A. Neboiss and K. Walker; 2♀ d'Entrecasteaux River, South Coast road, 14 Feb. 1988, A. Neboiss and K. Walker; 1♂ 2♀ Apsley River, 5 km, NW of Bicheno, 20 Dec. 1988, J. Jackson; ♂ ♀ Lake Pedder, shore N of Forest Creek, 10 Feb. 1999, J. Jackson; ♂ ♀ Maria Creek near Lake Pedder, 10 Feb. 1999, J. Jackson; 1♂ Pebbly Creek, about 50 m upstream of Lake Pedder, 10 Feb. 1999, J. Jackson; 3♂ 7♀ Lake Pedder, Frankland shore, 10 Feb. 1999, J. Jackson. All specimens in NMV.

The species was described fully by Kimmins *in* Mosely & Kimmins (1953) and further details and distributional data were added by Neboiss (1977). Wing venation (fig. 16F), male (fig. 16C) and female (fig. 16D, E) genitalia are illustrated here for ease of comparison.

Distribution
Tasmania, widespread throughout the state. Tasmanian endemic.

Daternomina quasitrulla sp. n.
Figs 16G, 16H, 18B

Type material
Holotype ♂ Tasmania, Fortescue Bay 43°08'S, 147°57'E, Tasman Penninsula [wet sclerophyl forest, collected in Mailaise trap], 7–9 Feb. 1989, D. Bickle (male genitalia prep. PT-1834 illustrated), NMV.

Length of forewing: ♂ 4.9 mm. Adults small, brownish, closely resembling the SW Australian species *Daternomina trulla* (Neboiss 1982) from the Albany area, but may be distinguished by details of male genitalia, particularly the robust mesal process at the base of inferior appendages.

Male genitalia (fig. 16G, H): abdominal sternite IX elongate, distal margin with a row of long bristles, which exceed the length of inferior appendages; tergite IX membranous, separated from the short membranous segment X by a strong ridge; superior appendages large, rather robust with elongate group of spines on upper mesal margin; inferior appendages fused, forming a short ventral plate, cleft apically; a robust mesal process, apically bent downward and slightly exceeding the length of inferior appendages.

Female unknown.

Etymology
Quasi (L) — simulating, like, in reference to the similarity to the SW Australian species *D. trulla.*

Distribution
SE province; known from type locality only. Tasmanian endemic.

Daternomina jacksonae sp. n.
Figs 17A–E, 18B

Type material
Holotype ♂ Tasmania, Lake Pedder, Frankland shore, 42°58'S, 146°09'E; 10 Feb. 1999, J. Jackson. Paratypes 7♂ 2♀ collected with holotype (male genitalia preps PT-2249 and female PT-2189 illustrated); 2♂ Lake Pedder impoundment WHA, 1 Mar. 1988, SC/JJ; 1♂ Lake Pedder, Frankland shore, 2 Mar. 1988,J. Jackson; 1♂ Lake Pedder, Teds Beach S corner, 4 Mar. 1988, J. Jackson; 1♂ Lake Pedder, Kostka Point, Cumberland shore, 2 Mar. 1988, J. Jackson; 1♂ 1♀ Stream E of Spring St. houses, Strathgordon, 13 Jan. 1999, J. Jackson. All specimens in NMV.

Other material examined
1♂ 10♀ Olga River, 19 km above Gordon River junction, 13 Jan. 1977, A. Neboiss; 1♀ Swamp near Olga River, 19 km above Gordon River junction, 13 Jan. 1977, A. Neboiss; 1♂ Louisa Creek, 25 Dec. 1978, S.F. McEvey; 1♂ Apsley River, 5 km NW of Bicheno, 20 Dec. 1988, J. Jackson (NMV).

Adults brown to dark brown; length of forewing ♂ 4.3–4.6 mm; ♀ 4.6–5.0 mm. This species closely resembles the SW Australian species *D. scindens*, but differs in genitalic details.

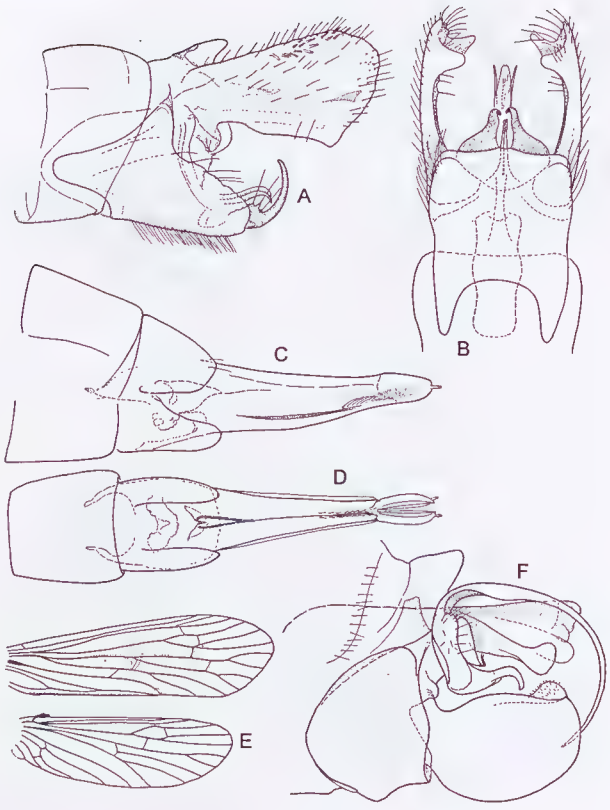

FIG. 17 — Daternomina jacksonae *sp. n.: (A) male genitalia lateral; (B) male genitalia ventral; (C) female genitalia lateral; (D) female genitalia ventral; (E) male wing venation. (F)* Polyplectropus lacusalbinae *Kimmins, male genitalia lateral.*

Male genitalia (fig. 17A, B) segment IX membranous dorsally, separated from the membranous segment X by a distinct ridge; superior appendages large, widened distally, lower margin with mesally directed distal lobe, inner surface of dorsal margin with elongate group of spines and a triangular mesal lobe near distal end. Inferior appendages upturned, claw-shaped; a pair of close, slender, curved mesal processes arising from the base; phallus straight, membranous.

Female abdomen (fig. 17C, D) slender, gradually tapered distally; sternite VIII widely divided meso-ventrally, forming two lateral plates, sternite IX elongate slender, with darkly pigmented, distally pointed, mesal margins at base.

Etymology
Named after Dr Jean Jackson for her contribution to knowledge of Tasmanian caddis flies.

Distribution
Tasmania, SW province. Tasmanian endemic.

FAMILY POLYCENTROPODIDAE

Polyplectropus Ulmer

Polyplectropus Ulmer, 1905: 103; Mosely & Kimmins 1953: 359.

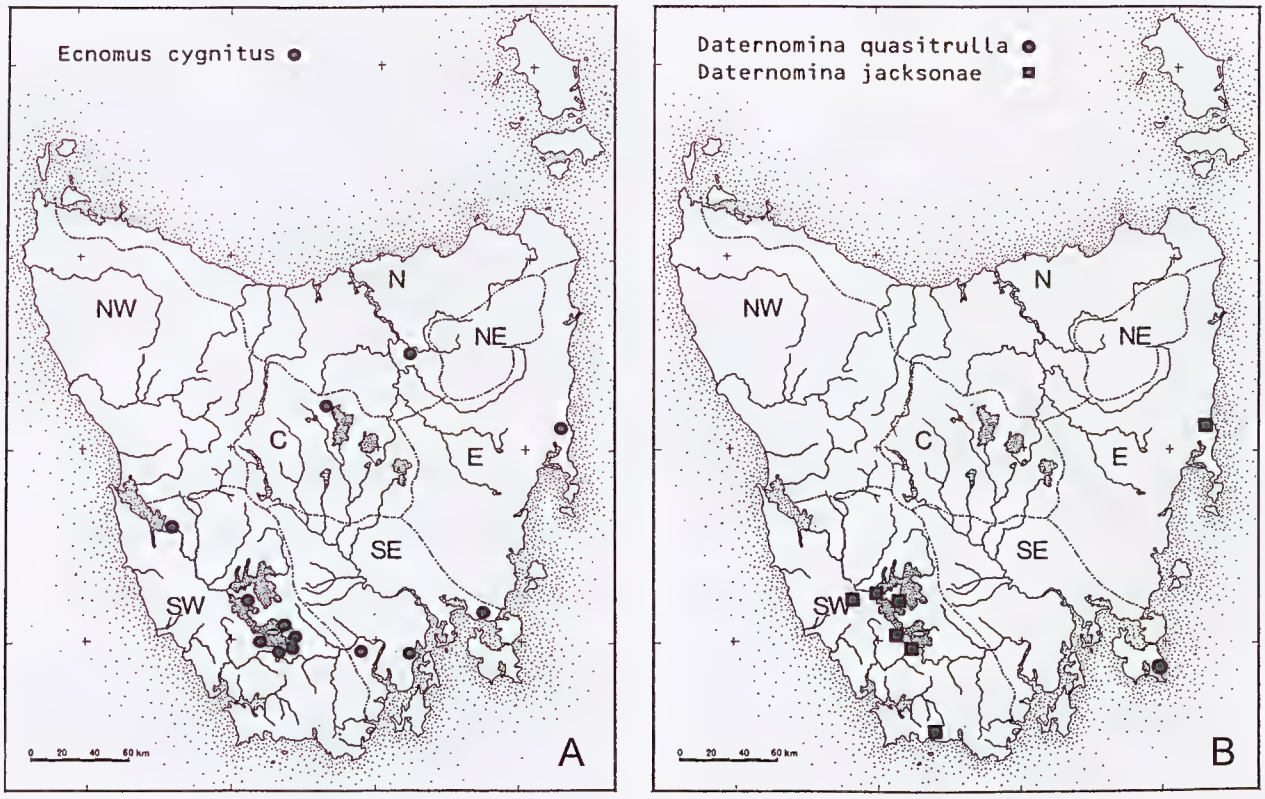

FIG. 18 — Distribution maps: (A) Ecnomus cygnitus *Neboiss; (B)* Daternomina quasitrulla *sp. n. and* D. jacksonae *sp. n.*

Type species
Polyplectropus flavicornis Ulmer, 1905 by monotypy.

Polyplectropus lacusalbinae Kimmins
Fig. 17F

Polyplectropus lacusalbinae Kimmins *in* Mosely & Kimmins, 1953: 363, fig. 249.

Material examined
Tasmania 1♂ Flinders Island, Pats River area, 3 Feb. 1963, N. Dobrotworsky (male genitalia prep. PT-1694 illustrated). This species is here recorded for the first time from Victoria — 1♂ Noojee, Loch Valley, 9 Apr. 1959, N. Dobrotworsky. All specimens in NMV.

Originally described from a single ♂ from Lake Albina, Mt Kosciusko, New South Wales, this species is now recorded more widely for first time. It resembles somewhat the New Zealand species *Polyplectropus puerilis* (McLachlan). Other species of the genus are known from South-West Pacific localities, and it would not be surprising if *P. lacusalbinae* is more widespread in Tasmania.

Diagnosis
Dark, greyish-brown species, forewing ♂ 6.3–8.0 mm with numerous golden irrorations; fork 1 present; hind wing smoky greyish brown with forks 2 and 5 only. Male genitalia (fig. 17F) segment IX dorsally membranous, fused with segment X; sternite IX strongly chitinised. Dorsal to inferior appendages is a complex sclerite, dorsal margin of which forms a long downwards curved strap-like spine; the second branch is in form of an elongate rounded lobe directed outward; a third, lower branch forms a down and outwardly directed hook; interior appendages single-segmented, robust with rounded dorso-mesal hairy lobe. Phallus cylindrical, lower margin developed into an elongate lateral flange with margin upcurved.

Female unknown.

Distribution
Flinders Island. Other states: Victoria, New South Wales.

Genus *Paranyctiophylax* Tsuda

Paranyctiophylax Tsuda, 1942: 265; Neboiss 1993: 110.

Type species
Paranyctiophylax kisoensis Tsuda, 1942 by original designation.

The generic concept of the genus *Nyctiophylax* Brauer was reviewed by Neboiss (1993). The genus *Paranyctiophylax* Tsuda was redefined to accommodate a distinct lineage of species previously included in *Nyctiophylax*. In this analysis 25 species were assigned to the genus *Paranyctiophylax*, among them also the only Tasmanian species, *P. repandus* (Neboiss, 1977).

The genus *Paranyctiophylax* is diagnosed as having forewing fork 1 absent, fork 3 present and anal veins distinctly looped and thickened near the junction; in the hind wing forks 1 and 3 absent, discoidal cell present and cell at the base of A2-A3 long; cross-vein closing cell distinctly separated from cross-vein Cu2-A1 and closer to the wing margin.

Paranyctiophylax repandus (Neboiss) Fig. 19A

Nyctiophylax repandus Neboiss, 1977: 65.
Paranyctiophyla repandus. Neboiss 1993: 107.

Holotype
♂ Tasmania, Scamander River, Upper Scamander, 9 Nov. 1972 (NMV).

Additional material examined
Tasmania 1♂ Sir John Falls, Cataract Creek, Gordon River tributary, 9 Jan. 1977, A. Neboiss *et al.* 5♂ 2♀ Franklin River Roaring Creek junction, 1 km above Gordon River, 8 Jan. 1977, A. Neboiss *et al.*; 3♂ 1♀ West Bay River, Margate, 6 Jan. 1977, A. Neboiss and P. Allbrook; 7♂ 1♀ Apsley River, 5 km NW of Bicheno, 20 Dec. 1988, J. Jackson. All specimens NMV.

Distribution
Tasmania, scattered localities NE, E, SE and SW provinces. Tasmanian endemic.

Genus *Tasmanoplegas* Neboiss

Tasmanoplegas Neboiss, 1977: 64.

Type species
Tasmanoplegas spilota Neboiss, 1977 by original designation.

Tasmanoplegas spilota Neboiss

Tasmanoplegas spilota Neboiss, 1977: 64.

Holotype
♂ Tasmania, West Arthur Plains, 26 Feb. 1965 (NMV).

Material examined
Tasmania 15♂ Strathgordon, Jan. 1977, J. Sedlacek; 1♂ Dove River below Dove Lake, 18 Jan. 1976, A. Wells; 3♂ Franklin River, buttongrass plain, 14 Jan. 1983, ANZSES expedition; 2♂ Swamp near Olga River, 12 km above Gordon River junction, 12 Jan. 1977, A. Neboiss; 2♂ small trickle flowing into Lake Ayr, Cradle Mountain-Lake St Clair National Park, 16 Jan. 1990, J. Dean and D. Cartwright; 5♂ Lake St Clair, 21 Dec. 1999, M. Driessen. All specimens in NMV.

The additional localities are all associated with small streams on buttongrass plains. The species appears to be rather widely distributed and locally common. The preparation PT-256 of the original and only female is somewhat damaged and thus comparison with the specimens from the south coast is very difficult.

Distribution
Tasmania, scattered localities NW and SW provinces. Tasmanian endemic.

Tasmanoplegas sp. Fig. 19B–D

Material examined
Tasmania 2♀ Cavers' camp, NE New River Lagoon, 31 Dec. 1978, S.E. McEvey (genitalia prep. PT-1712 illustrated).

Length of forewing: ♂ unknown; ♀ 9.7 mm.

The wing pattern (fig. 19B) of these south coast specimens appears to be very similar to that of *T. spilota.* However, the only known female of *Tasamanoplegas spilota* is distinctly smaller (forewing 8 mm). The female genitalia, although very similar, also show some differences, but with the absence of males from the south coast locality, the species identity remains unresolved.

FAMILY HYDROPSYCHIDAE

Genus *Cheumatopsyche* Wallengren

Cheumatopsyche Wallengren, 1891: 142; Neboiss 1977: 66.

Type species
Hydropsyche lepida Pictet, 1834 (Europe) by monotypy.

Moderate-sized, slender insects; wings usually greyish-brown to yellowish-brown, more or less distinctly mottled. Cross-veins M_{3+4}-Cu1, and Cu1-Cu2 in forewing close to each other. Hind wing fork 1 absent.

The genus is widely distributed in Australia, but until recently only one species, *Cheumatopsyche modica* (McLachlan), was recognised. Detailed studies of larvae by Dean (1999) reveal a far greater diversity of species. Previously all specimens from Tasmania were ascribed to *Cheumatosyche modica* (Neboiss 1977), but the existence was noted of two distinct forms, one marginally paler and larger, the other slightly smaller and darker. Closer examination of genitalic characters revealed subtle but constant differences in character states, enabling their separation into two distinct species. This division is supported by the distinct larval types as recognised by Dean (1999). An ovoid cellular structure/patch (fig. 20I) is located on pleurite of segment IV. This structure is present in females of both Tasmanian species as well as in the females of *C. modica* from the type locality — Merri Creek, Victoria. This may be regarded as a generic character.

In Tasmania *Cheumatopsyche alampeta* sp. n. appears to be more widespread than *Cheumatopsyche deani* sp. n. It also appears to be more common in mid to late summer (December–January) and is more often associated with smaller streams than is *C. deani* sp. n. A single male from Lake Tahune, Frenchmans Cap area, 28 Jan. 1988 (Coll. J. Jackson; PT-2164) may represent another undescribed species, but more material is required to verify its identity.

When the drawing of *Cheumatopsyche modica* type became available (courtesy of P. Barnard, NMH, pers. comm.) it was apparent that none of the Tasmanian specimens conforms with *C. modica* in all character states, particularly in details of segments IX and X, as well as inferior appendages in males and the shape of scleritic cavity in females (fig. 20C, G). Thus new names are established for the Tasmanian species and at this stage, the name *C. modica* is excluded from the Tasmanian fauna and replaced with *C. deani* sp. n. and *C. alampeta* sp. n.

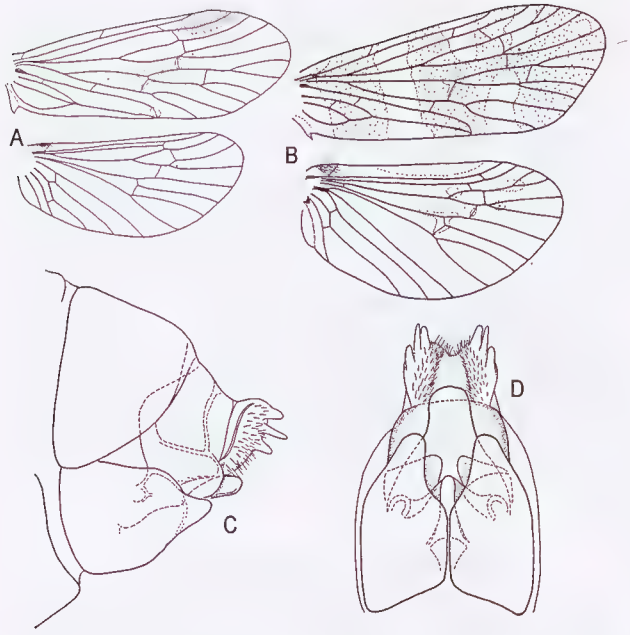

FIG. 19 — (A) Paranyctiophylax repandus (Neboiss), wing venation. (B–D) Tasmanoplegus *sp. female: (B) wing venation; (C) female genitalia lateral; (D) female genitalia ventral.*

Cheumatopsyche deani sp. n.
Fig. 20A–D

Type material

Holotype ♂, Tasmania, Leven River, Heka, 17 Nov. 1972, A. Neboiss (male genitalia prep. PT-2235 illustrated). Paratypes 15♂ 15♀ same data as for holotype (female genitalia prep. PT-2234 illustrated); 3♂ 9♀ Mersey River, Liena, 16 Nov. 1972, A. Neboiss. All specimens in NMV.

Other material examined

Tasmania, 1♂ 86♀ Scamander River, Upper Scamander, 9 Nov. 1972, A, Neboiss; 2♀ South Esk River, Evandale, 1 Mar. 1967, A. Neboiss. All specimens in NMV.

Description

Forewings greyish-brown to yellowish-brown, indistinctly mottled. Length of forewing: ♂ 9.8–10.4 mm; ♀ 10.1–11.0 mm.

Male genitalia (fig. 20A, B) segment IX in lateral view with basal margin rather uniformly curved, the height:length proportions usually 2.1:1; dorsal segment X broad, subquadrate with broad mesal excision, apico-lateral lobes short, rounded; pre-anal appendages squat, rounded; inferior appendages slender, harpago about 1/4 to 1/5 length of coxite; distal end of coxite gradually and only slightly widened.

Female genitalia (fig. 20C, D) sternite VIII somewhat rounded, margins not obviously, if at all, pigmented; scleritic cavity (Nielsen 1980), also known as clasper receptacle, with distal margin usually extending further ventrad than basal margin, opening about full width of the cavity; dorsal separation of cavities usually is slightly less than one width of each cavity.

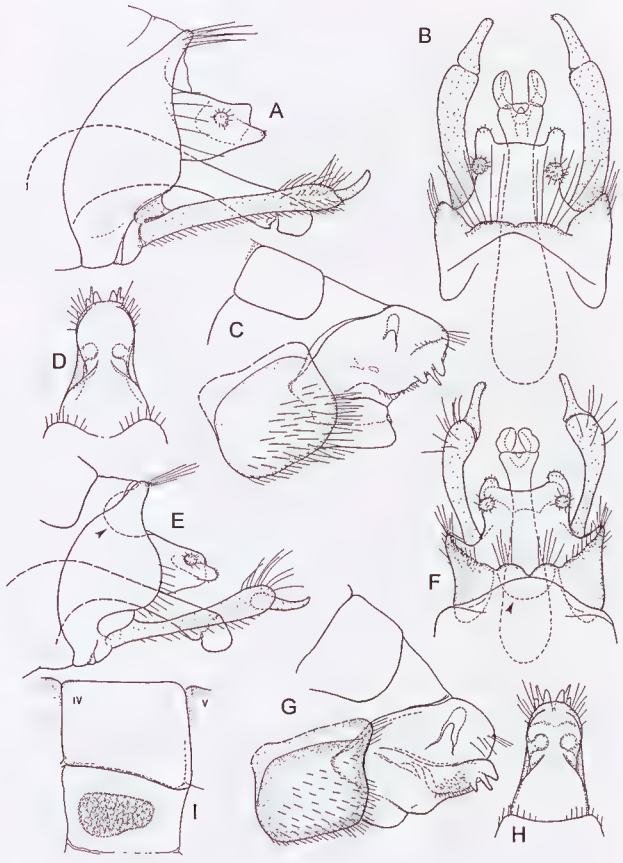

FIG. 20 — (A–D) Cheumatopsyche deani *sp. n. A, B male genitalia: (A) lateral; (B) dorsal. (C, D) female genitalia: (C) lateral; (D) dorsal. (E–I)* Cheumatopsyche alampeta *sp. n. (E, F) male genitalia: (E) lateral; (F) dorsal. (G, H) female genitalia: (G) lateral; (H) dorsal. (I) tergite and pleurite IV lateral.*

Distribution

In Tasmania, usually found in slow flowing lowland streams. Other states: probably Victoria and New South Wales.

Cheumatopsyche alampeta sp. n.
Fig. 20E–I

Type material

Holotype ♂ Tasmania, Derwent River, 2 km NW of Derwent Bridge, 12 Feb. 1971, A. Neboiss, NMV. Paratypes 15♂ 15♀ same data as for holotype. (Male genitalia prep. PT-2232 and female PT-2231 illustrated.)

Other material examined

Tasmania, 1♂ Derwent River, 3 km W of New Norfolk, 7 Dec. 1974; 9♂ 8♀ Plenty River, 6 km E of Moogara, 7 Dec. 1974, A. Neboiss; 22♂ 20♀ West Bay River, Margate, 6 Jan. 1977, A. Neboiss; 7♂ 1♀ Shannon River, Wihareja, 29 Nov. 1982, W. Fulton; 1♂ 1♀ Shannon River, 15 Dec. 1982, W. Thompson; 2♂ 2♀ Liawanne, laboratory aquarium, Dec. 1982, W. Fulton; 11♂ 1♀ Black Bobs Creek, 15 km N of Ouse, 9 Dec. 1974, A. Neboiss; 4♂ 19♀ Ouse River, 8 km W of Miena, 14 Dec. 1982, W. Fulton; 1♂ 1♀ Bronte Park, 12 km NNE, 20 Jan. 1983, J. Cardale; 3♂ 16♀ Hellyer River Gorge, 9 Feb. 1971, A. Neboiss; 44♂ 48♀ Mersey River,

Liena, 16 Nov. 1972, A. Neboiss; 1♂ 1♀ Leven River, Heka, 17 Nov. 1972, A. Neboiss; 28♂ 14♀, Macquarie River, 8 km W of Campbelltown, 9 Nov. 1972, A. Neboiss; 3♂ 2♀ Lake River, 5 km SW Delmont, 9 Nov. 1972, A. Neboiss; 2♂ Tooms Lake, 4 Dec. 1974, A. Neboiss; 2♂ 1♀ Apsley River, 5 km NW of Bicheno, 20 Dec. 1988, J. Jackson; 1♂ Styx River, Westerway, 23 Nov. 1972, A. Neboiss; 11♂ 1♀ Scamander River, Upper Scamander, 9 Nov. 1972, A. Neboiss; 1♂ Lilydale, small creek, 2 km N, 16 Dec. 1974, A. Neboiss. All specimens in NMV.

Description

Adults with general colour of forewings dark blackish-brown with slight mottling. Length of forewing: ♂ 7.9–8.4 mm; ♀ 7.8–9.0 mm. Male genitalia (fig. 20E, F) segment IX in lateral view with basal margin depressed dorsally; the height:length proportions approx. 1.9:1; lateral lobe more pronounced than in *deani*; segment X broad, mesal excision broad; apical apico-lateral lobes short, rounded; pre-anal appendages squat, rounded; the base of tergite X forms an obvious rounded cavity within the dorsal section of segment IX clearly visible in cleared preparations; inferior appendages slender, harpago about 1/4 length of coxite; distal end of coxite widened, almost club-like and usually with darker pigmentation.

Female genitalia (fig. 20G, H), sternite VIII somewhat angular with apico-dorsal angle more or less produced; all margins more or less strongly pigmented; scleritic cavity with both margins of approximately the same length, opening less than full width of the cavity, distal margin with an obvious bend about midway; dorsal separation of cavities about half to one width of the cavity.

Etymology

Alampetos (Cr.) — dark, obscure in reference to its generally darker colour.

Distribution

Tasmania, widespread. Other states: probably Victoria.

Genus *Diplectrona* Westwood

Diplectrona Westwood, 1840: 49; Neboiss 1977: 71.

Type species

Aphelocheira flavomaculata Stephens, 1836 by original designation.

The species listed from Tasmania by Neboiss (1977) are here revised. It is now confirmed (Neboiss 1986) that *Diplectrona bispinosa* Jacquemart belongs to the genus *Austropsyche* Banks, and the type locality is indeed Sassafras, Victoria. Thus, this species is removed from the Tasmanian list.

Additional material collected during the last 20 years has led to further clarification of this group. The re-examination of the type of *Diplectrona castanea* Kimmins reveals that the original figures published by Mosely & Kimmins (1953: fig. 237b–d) fail to show all the details critical for species identification: particularly, these authors omit the shape of lateral margin of segment IX, and some details of the phallic structures. Examination of these features indicated that *Diplectrona lyelli* Neboiss, 1977 is synonymous with *D. castanea*.

Species of the genus *Diplectrona* s.l. in Australia may be divided into several more or less distinct groups, two of which are represented in Tasmania. One species *D. castanea* belongs to the *Diplectrona* s.l., but two others, *D. tasmanica* Jacquemart and a new species, are referred to a new genus, *Diemeniluma*.

The genera *Diplectrona* and *Diemeniluma* in Tasmania may be distinguished by the following characteristics.

Diplectrona: head with five setal warts (fig. 21A). Male genitalia with lateral margin of segment IX extended into a distinct triangular lobe; phallic apparatus with parameres. Female genitalia with sternite VIII consisting of two sclerites separated ventro-mesally.

Diemeniluma: Head with four setal warts (fig. 22A), antero-mesal wart absent. Male genitalia with lateral margin of segment IX almost straight, mot extended into a lobe; phallic apparatus simple, base bulbous, parameres absent. Female genitalia with sternite VIII consisting of a single sclerite.

Diplectrona castanea Kimmins
Fig. 21A–D

Diplectrona castanea Kimmins *in* Mosely & Kimmins, 1953: 342; Neboiss 1977: 72.
Diplectrona lyelli Neboiss, 1977: 72. New synonym.

Holotype of *Diplectrona castanea*, ♂ Tasmania, National park, 3000 ft, 26 Dec. 1936 (BMNH); (male genitalia illustrated).
Holotype of *Diplectrona lyelli*, ♂ Tasmania, King River, 5 Nov. 1961 (NMV).

Additional material examined

Tasmania, 1♂ Hellyer River Gorge, 2 Dec. 1972, P. Zwick (paratype of *D. lyella*; aedeagus prep. PT-1043 illustrated); 1♂1♀ Nelson Falls, 3 Nov. 1998, J. Jackson; 1♂ Little Florentine River upstream of Gordon road, 2 Dec. 1998, J. Jackson; 1♀ Bull Creek, Cradle Mountain road, 12 Dec. 1974, A. Neboiss; 1♂ tributary of Darwin River, West Coast, 31 Oct. 1976, P. Albrook; 1♀ Arrowsmith Creek, 18 km SW of Derwent Bridge, 9 Dec. 1974, A. Neboiss (female genitalia prep. PT-1068 illustrated); all specimens in NMV. 1♂ Mt Burrow, 11 km EbyN Nunamara, 7 Feb. 1983, J. Cardale (ANIC).

Diagnosis

Dark blackish-brown in colour. Length of forewing ♂ 8.4–10.0mm; ♀ 10.2–12 mm. Male abdominal segments VI and VII each with a pair of globular internal sacks (glands); genitalia (fig. 21B); segment IX lateral margin with distinct dorsally pointed lobe; inferior appendages stout, coxite slightly widened at apex, about 2.5 times length of harpago. Phallus (fig. 21C), with two pairs of parameres, the inner pair slender, almost as long as aedeagus, outer pair shorter, upcurved; aedeagus with lateral flanges at basal half; a short, triangular apically pointed plate at base; thin lateral flaps on each side.

Female abdomen (fig. 21D) tergite IX with small latero-ventral pockets at base; sternite VIII deeply divided ventro-mesally.

Distribution

Tasmania, NW, SW, SE and NE provinces. Tasmanian endemic.

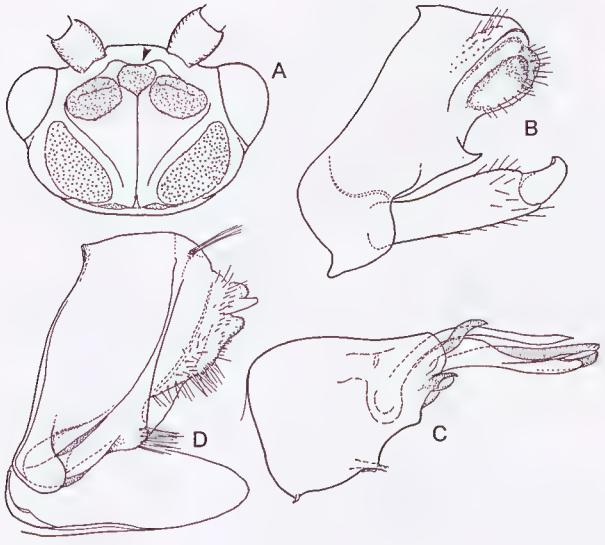

FIG. 21 — Diplectrona castanea *Kimmins: (A) male head dorsal; (B) male genitalia lateral; (C) phallus lateral; (D) female genitalia lateral.*

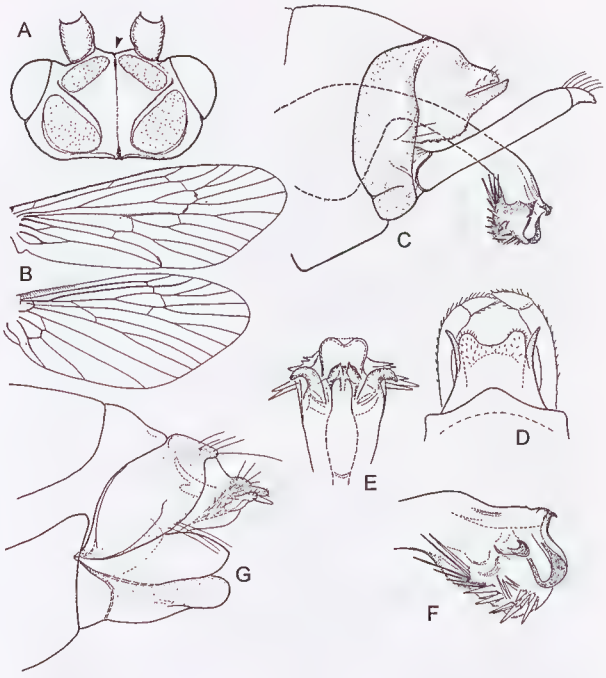

FIG. 22 — Diemeniluma tasmanica *(Jacquemart): (A) male head dorsal; (B) male wing venation; C) male genitalia lateral; (D) male genitalia dorsal; (E) tip of phallus ventral; (F) tip of phallus lateral; (G) female genitalia lateral.*

Genus *Diemeniluma* gen.nov.
Fig. 22A, B

Type species
Diplectrona tasmanica Jacquemart, 1965, by present designation.

Diagnosis
Adult head dorsally with two pairs of large setal warts; antero-mesal wart absent. Forewing with cross-vein C-Sc present. Lateral filament on abdominal sternite V present in both sexes. Female abdominal sternite VIII entire, not divided ventro-mesally; segment IX without lateral scleritic cavity, sternite IX three-lobed.

Description
Wing venation (fig. 22B) regular and similar in both sexes; discoidal cell rather short and present in both wings. Forewing with forks 1–5 present, fork 2 sessile, anal veins looped basally and only one (A-1) extends distally, reaching wing margin at arculus together with Cu2. Hind wing rather broad, Sc and R1 not curved, but more or less parallel to costal margin; forks 1, 2, 3 and 5 present, fork 1 with short footstalk, fork 2 sessile. Head dorsally with pair of undivided antero-lateral setal warts and larger, semi-ovoid postero-lateral setal warts; antero-mesal setal wart absent. Antennae slender, about as long, or slightly shorter than forewing; segments somewhat cylindrical, each with pale encircling ring at about basal third. Lateral filaments on abdominal sternite V present in both sexes, slender and. extending to the distal margin of segment. In males there are two pairs of rounded membranous sacs within segments VI and VII, their diameter less than the length of the segment.

Male genitalia with segment IX annular, dorsally fused with segment X; in lateral view a dark longitudinal inner ridge is located across segment at the base of inferior appendage. (This is not present in other Australian Diplectroninae species.) Inferior appendages slender, harpago, small, phallus slender, broad based, apex enlarged and armed with spines.

Female differs from all other Australian *Diplectroninae* by having sternite VIII entire, not divided meso-ventrally; segment IX without lateral sclerotic cavity. Mid-legs not dilated.

This genus is restricted to Tasmania, where it is represented by two species. They may be separated by the shape and position of the lateral process on segment X and by the arrangement of spines at the apex of the phallus.

Etymology
Luma (Latin) — thorn, in reference to the spiny apex of phallus, in combination with Tasmania's original name, Van Diemen's Land.

Diemeniluma tasmanica (Jacquemart)
Fig. 22A–G

Diplectrona tasmanica Jacquemart, 1965: 27; Neboiss 1977: 73, fig. 364.

Holotype
♂ Tasmania, Cradle Mountain, 12 Jan. 1923, A. Tonnoir (IRScNB). (Type seen.)

Additional material examined
1♂ 10 km SW of Queenstown, 11 Feb. 1971, A. Neboiss (male genitalia prep. PT-515 illustrated); 1♀ Gordon River, 2 km below Serpentine River junction, 12 Jan. 1977, A. Neboiss (female genitalia prep. PT-1067 illustrated); 1♂ Lake Tahune, Frenchmans Cap area, 28 Jan. 1988, J. Jackson. All specimens in NMV.

Length of forewing (fig. 22B) ♂ 6.0–6.5 mm; ♀ 6.4 mm; colour dark to medium brownish; median cell slightly longer than discoidal cell; fork 1 with short footstalk.

Male genitalia (fig. 22C, D) with segment IX short, lateral angles rounded, dorsally fused with segment X; apical margin of segment X with broad mesal recess, produced distally; lateral digital process slightly exceeding the mesal section. Inferior appendages long, harpago short, curved inward, apically pointed. Phallus slender, curved downward, terminating with apico-ventral cluster of spines, larger, curved apico-lateral spine on each side of apical sclerite.

Female (fig. 22G) tergite IX without scleritic cavity; sternite IX semi-membranous, 3-lobed.

Distribution
Tasmania, known from NW and northern SW provinces (Neboiss 1977). Tasmanian endemic.

Diemeniluma serrula sp. n. Fig. 23A–E

Type material
Holotype ♂ Tasmania, Hartz Mountains, Jan. 1977, J. Sedlacek. Paratypes 4 ♂ collected with holotype (male genitalia prep. PT-634 illustrated), NMV.

Length of forewing: ♂ 5.9–6.3 mm; colour dark brownish.

Male genitalia (fig. 23A–C) similar to those of *D. tasmanica* but differing in details. Segment X in dorsal view produced, almost hood-like, with small narrow cleft apically; lateral digital process situated slightly lower than in *tasmanica*; lower margin of segment irregularly serrate. Inferior appendages slender, harpago short, curved inward, pointed apically. Phallus slender, curved downward, apico-lateral spines straight, mid-laterally three short, distally directed spines on each side.

Female unknown.

Etymology
Serra (Latin) — saw, in reference to the serrate segment X.

Distribution
Known from type locality only in the eastern part of SW province of Tasmania. Tasmanian endemic.

FAMILY PLECTROTARSIDAE

Genus *Plectrotarsus* Kolenati

Plectrotasrsus Kolenatis 1848: 94; Mosely & Kimmins 1953: 21; Neboiss 1977: 75.

Type species
Plectrotarsus gravenhorsti Kolenati, 1848 by monotypy.

Plectrotarsus gravenhorsti Kolenati

Plectrotarsus gravenhorsti Kolenati 1848: 94; Neboiss 1977: 75; 1987: 135.

Holotype
♂ 'Australia occidentali' in Naturhistorisches Museum, Vienna.

Additional material examined
Tasmania, 5♂♀ Hatfield River on Murchison Highway, 20 Jan. 1976, A. Wells; 1♀ small creek W side Great Lake, 17 Jan. 1976, A. Wells. All specimens in NMV.

Distribution
Tasmania, scattered localities NW, N, C and SE provinces. Other states: Victoria, New South Wales.

Plectrotarsus tasmanicus Mosely

Plectrotarsus tasmanicus Mosely 1936: 396; Mosely & Kimmins 1953: 21; Neboiss 1977: 76.

Holotype
♂ Tasmania, Miena, Dec. 1930 (BMNH).

Additional material examined
Tasmania, ♂ ♀ (numerous) Lake Ayr, Cradle Mountain-Lake St Clair National Park, 16 Jan. 1990, J. Dean and D. Cartwright; 1♂ Iris River, Cradle Mountain National Park, 19 Jan. 1976, A. Wells; 1♀ Lake Tahune, Frenchmans Cap area, 28 Jan 1988, J. Jackson; 2♂ Lake Whitham, Frenchmans Cap area, 27 Jan. 1988, J. Jackson; ♂ ♀ (numerous) lake on right bank of Gordon River 8 km below Butler Island, 9 Jan. 1977, D. Coleman and A. Neboiss; ♂ ♀ (numerous) Cradle Valley, 13 Jan. 1976, A. Wells (on *Leptospermum*); 1♂ Little Pine Lagoon, 16 Feb. 1967, E.F. Riek; ♂ ♀ (numerous) and larval cases, Artichoke Valley, Frenchmans Cap area, 29 Jan. 1988, J. Jackson; ♂ ♀ (numerous) Swamp near Olga River, 19 km above Gordon River junction, 13 Jan. 1977, A. Neboiss. All specimens in NMV.

Distribution
Tasmania, C, NW and SW provinces and King Island. Tasmanian endemic.

Genus *Liapota* Neboiss

Liapota Neboiss 1959: 95.

Type species
Liapota lavara Neboiss, 1959 by original designation.

Liapota lavara Neboiss

Liapota lavara Neboiss 1959: 95; 1977: 76.

Holotype
♂ Tasmania, Cradle Mountain, (no date), J. Carter and A.M. Lea (SAM).

Distribution
Tasmania, widely distributed throughout the western provinces of the state. Tasmanian endemic.

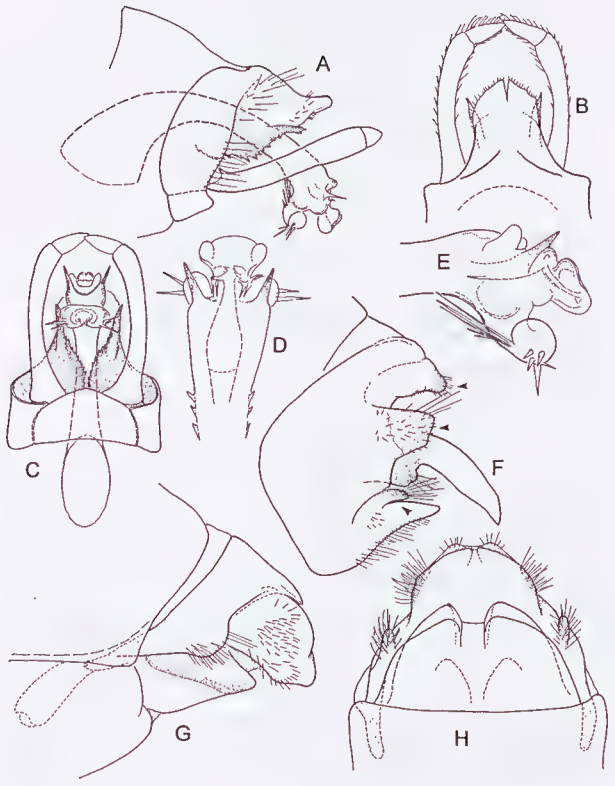

FIG. 23 — (A–E) Diemeniluma serrula *sp. n., male genitalia: (A) lateral; (B) dorsal; (C) ventral; (D) tip of phallus ventral; (E) tip of phallus lateral. (F) Archaeophylax ochreus Mosely, male genitalia lateral. (G, H))* Tascuna ignota *Neboiss, female genitalia: (G) lateral; (H) ventral.*

Genus *Nanoplectrus* Neboiss

Nanoplectrus Neboiss 1977: 77.

Type species
Nanoplectrus truchanasi Neboiss, 1977 by original designation.

Nanoplectrus truchanasi Neboiss

Nanoplectrus truchanasi Neboiss 1977: 77.

Holotype
♂ Tasmania, Junction Creek, West Arthur Plains, 6 Feb. 1966 (NMV).

Distribution
Tasmania, endemic (known only from the type locality, from a single male specimen).

FAMILY LIMNEPHILIDAE

Genus *Archaeophylax* Kimmins

Archaeophylax Kimmins *in* Mosely & Kimmins, 1953: 27; Neboiss 1977: 78.

Type species
Archaeophylax ochreus Mosely *in* Mosely & Kimmins, 1953 by original designation.

Archaeophylax ochreus Mosely
Fig. 23F

Archaeophylax ochreus Mosely *in* Mosely & Kimmins 1953: 27; Neboiss 1977: 78.
Archaeophylax vernalis Neboiss 1977: 79. New synonym.

Holotype
♂ of *Archaeophylax ochreus*, Tasmania, Cuvier River, Feb. 1941 (BMNH).
♂ of *Archaeophylax vernalis* Tasmania, Lake Pedder, 12 Mar. 1972 (NMV).

In recent years a considerable number of specimens have been accumulated in collections from numerous localities throughout the western provinces of Tasmania. Detailed examination of this material shows that male genitalic structures are variable in size and shape (as indicated by arrows on fig. 23F), the variability fully overlapping the putative distinguishing features of *A. vernalis*. Thus, the name *Archaeophylax vernalis* is here suppressed as a junior synonym of *Archaeophylax ochreus*.

Additional localities
2♂ 1♀ Old River and Collingwood River junction, 10 Feb. 1988, A. Neboiss; 4♂ Sandfly Creek at Scotts Peak road, 9 Feb. 1988, K.Walker and J. Jackson; 1♂ Dozer Creek 100 m downstream of Gordon road, 4 Mar. 1999, J. Jackson; 3♂ 1♀ Lake Tahune, Frenchmans Cap area, 28 Jan. 1988, J. Jackson; 4♂ Maria Creek nr Lake Pedder, 10 Feb. 1999, J. Jackson; 1♂ Scotts Peak Dam, Serpentine impoundment, 23 Mar. 1985, P. Greenslade; 1♂ Arve River, 3 Feb. 1983, J.C. Cardale; 1♂ Little Florentine River upstream of Gordon road, 2 Dec. 1998, J. Jackson; 1♂ same loc., 26 Jan 1999, J. Jackson; 1♂ Huon River at Tahune Bridge, 14 Jn. 1988, SC/CF; 1♂ E-Arthur Ranges, 1 km W of Federation Peak, alt 1000 m, 11 Feb. 1988, P.B. McQuillan; 4♂ Wedge River above Gordon road, 26 Jan. 1999, in forest, J. Jackson; 3♂ Franklin River upstream of Lyell Highway, 16 Feb. 1999, J. Jackson; 3♂ Condominion Creek, Scotts Peak Dam road, 26 Jan. 1999, J. Jackson; 1♂ Dozer Creek below Gordon road, 4 Mar. 1999, J. Jackson; 1♂ Doctors Creek at Lyell Highway nr Breona, 9 Feb. 2001, R. Walker; 1♂ Pinetree Rivulet, Lake Highway nr Breona, 9 Feb. 1001, R. Walker. All specimens in NMV.

Distribution
Tasmania, widespread. Other states: Victoria, New South Wales.

FAMILY OECONESIDAE

Genus *Tascuna* Neboiss

Tascuna Neboiss, 1975: 82; Neboiss 1977: 83.

Type species
Tascuna ignota Neboiss, 1975 by original designation.

Tascuna ignota Neboiss
Fig. 23G, H

Tascuna ignota Neboiss, 1975: 82; Neboiss 1977: 83.

Holotype
♂ Tasmania, Waldheim, Cradle Mountain National Park, 7 Feb 1971 (NMV).

Additional material examined
1♂ near Timber Creek close to Lake Pedder, 10 Feb. 1999, J. Jackson; 3♂ Condominium Creek, Scotts Peak Dam road, 26 Jan. 1999, J. Jackson; 2♂ Red Tape Creek, Scotts Peak Dam road, 26 Jan. 1999, J. Jackson; 2♂ Strathgordon, Jan. 1977, J. Sedlacek; 5♂ Old River and Collins River junction, 10 Feb. 1988, A. Neboiss; 1♂ Franklin-Gordon River junction, ANZSES expedition base camp, 20 Jan, 1983; 1♂ Ropeway Creek, 400 m below Smith and Gordon River junction, 2 Feb. 1977, D. Coleman *et al.*, 1♀ Roaring Creek-Franklin River junction, 8 Jan. 1977, A. Neboiss *et al.* (♀ genitalic prep. PT-1377 illustrated); 1♂ Wedge River above Gordon road, 26 Jan. 1999, J. Jackson; 1♂ Pebbly Creek, 50 m upstream from Lake Pedder, 25 Nov. 1998, J. Jackson; 1♂ same loc., 10 Feb. 1999, J. Jackson. All specimens NMV.

Length of forewing: ♂ 14.5–17 mm; ♀ 18 mm.

Description of female: in general appearance similar to male, but wing colouring and mottling appear to be less intense. Female abdomen bluntly rounded apically (fig. 23G, H); sternite VI with small gland opening laterally near anterior margin; tergite X produced mesally, somewhat triangular; sternite X flattened ventrally; lateral pockets are situated between apico-lateral angle of tergite IX and tergite X.

Distribution
Tasmania, restricted to NW and SW provinces. Tasmanian endemic.

FAMILY CONOESUCIDAE

The family Conoesucidae, together with Helicophidae, Calocidae and Antipodoecidae, was studied in detail by Jackson (1991) in her unpublished PhD thesis. The classification was analysed, immature stages described and family relationships discussed. Chromosome analyses were applied for elucidation of phylogenetic relationships. The family Conoesucidae in Tasmania is represented by five genera and 19 species. Because of lack of material Jackson (1991) excluded *Costora iena* Mosely and *Lingora vesca* Neboiss. She also suggested that *L. vesca* may simply be a malformed *Lingora aurata* Mosely (Jackson, pers. comm.) because further specimens collected at the type locality of *vesca* proved to be typical *L. aurata.*

The genus *Costora* in Tasmania is represented by eight species. Jackson (1991) recorded a considerable number of additional localities for almost all species. It is rather surprising, however, that *Costora iena* Mosely has not been recorded since its original capture in 1934. All other species are widely distributed with the exception of *Costora krene* Neboiss, which appears to be restricted to the SW province, between Strathgordon and Melaleuca. Only two species — *Costora delora* Mosely and *Costora ebenina* Neboiss are known to occur also in SE mainland Australia; all others are endemic to Tasmania.

The validity of the *Lingora-Hampa-Matasia* group of genera was also questioned by Jackson (1991). The generic separations are based on male characters alone (Mosely & Kimmins 1953), and studies of females and immature stages indicate closer relationships (Jackson 1991). Further studies are required to resolve this question.

Genus *Conoesucus* Mosely

Conoesucus Mosely, 1936; Neboiss 1977: 109.

Type species
Conoesucus fromus Mosely by original designation.

Key to Tasmanian species of *Conoesucus* males (based on the key given by Neboiss (1977), with addition of species described by Jackson (1998)):

1. Abdominal sternite VII with broad spatulate ventral process 2
   Abdominal sternite VII without broad spatulate process 3

2. Abdominal segment IX with lateral margin produced into a subtriangular lobe ..... *norelus*
   Abdominal segment IX with lateral margin curved ..... *fromus*

3. Abdominal segment X in lateral view slightly curved upwards, margins parallel, apex broad and rounded ..... *digitiferus*
   Abdominal segment X in lateral view with margins not parallel, broadening, then tapering to apex 4

4. Abdominal segment X turned upwards at almost a right angle, tapering to somewhat triangular apex ... 5
   Abdominal segment X turned only slightly upwards, apex triangular, pointed, segment IX dorsal process stout ..... *notialis*

5. Maxillary palp segment 3 completely lacking sclerotisation ..... *nepotulus*
   Maxillary palp segment 3 sclerotised at base 6

6. Maxillary palp segment 3 about 3X length of segment 2 ..... *brontensis*
   Maxillary palp segment 3 about equal in length to segment 2 ..... *adiastolus*

Conoesucus fromus Mosely
Fig. 24A

Conoesucus fromus Mosely, 1936: 409; Mosely & Kimmins 1953: 88; Neboiss 1977: 109; Jackson 1991: 54.

Holotype
♂ Tasmania, Miena, Great Lake. Dec. 1930 (BMNH).

Distribution
Tasmania, widespread, including Flinders Island; not recorded from mid-east and coastal southwest. Not recorded outside Tasmania.

Conoesucus digitiferus Jacquemart
Fig. 24B

Conoesucus digitiferus Jacquemart, 1965: 9; Neboiss 1977: 111; Jackson 1991: 53.

Holotype
♂ Tasmania, Cradle Mountain, 12 Jan. 1923 (IRScNB).

Distribution
Tasmania, widespread in NW and SW provinces, few records from SE province — locally common. Not recorded outside Tasmania

Conoesucus norelus Mosely
Fig. 24C

Conoesucus norelus Mosely *in* Mosely & Kimmins, 1953: 90; Neboiss 1977: 110; Jackson 1991: 56.

Holotype
♂ Tasmania, New Norfolk, Mar. 1938 (BMNH).

Distribution
Tasmania, widespread. Not recorded outside Tasmania.

Conoesucus brontensis Neboiss
Fig. 24D

Conoesucus brontensis Neboiss, 1977: 112; Jackson 1991: 52.

Holotype
♂ Tasmania, 5 km W of Bronte, 8 Nov. 1972 (NMV).

Diagnosis
Distinguished from *adiastolus* by sharply upturned apex of segment X and maxillary palp with segment 3 long and sclerotised at base.

Distribution
Tasmania, scattered through western half of the state, but rather rare. Not recorded outside Tasmania.

Conoesucus nepotulus Neboiss
Fig. 24E

Conoesucus nepotulus Neboiss, 1977: 111; Jackson 1991: 55.

Holotype
♂ Tasmania, Dip River Falls, 1 Dec. 1974 (NMV).

Distribution
Tasmania — widespread through western part of the State. Not recorded outside Tasmania.

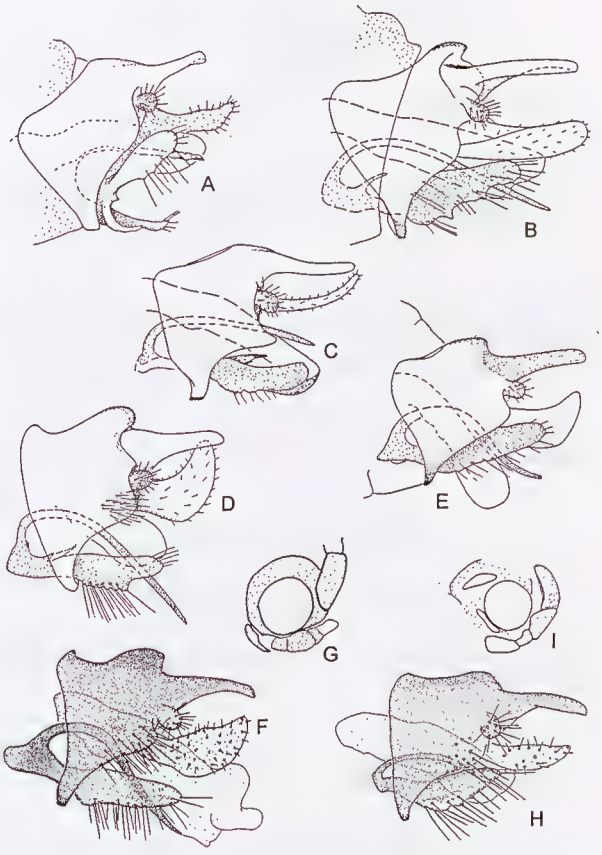

FIG. 24 — Conoesucus *spp. (A–F) male genitalia lateral: (A)* C. fromus *Mosely; (B)* C. digitiferus *Jacquemart; (C)* C. norelus *Mosely; (D)* C. brontensis *Neboiss; (E)* C. nepotulus *Neboiss; (F)* C. adiastolus *Jackson [from Jackson 1998]. (G)* C. adiastolus *Jackson [from Jackson 1998], male head lateral. (H)* C. notialis *Jackson [from Jackson 1998], male genitalia lateral. (I)* C. notialis *Jackson [from Jackson 1998], male head lateral.*

Conoesucus adiastolus Jackson
Fig. 24F, G

Conoesucus adiastolus Jackson, 1998: 134; Jackson 1991: 50.

Holotype
♂ Tasmania, Gordon River, 2 km downstream of Serpentine junction, 12 Jan. 1977 (NMV).

Diagnosis
Abdominal sternite VII without broad spatulate process; segment X apically turned upwards; maxillary palp segment 3 about as long as segment 2, basal part sclerotised (fig. 24G).

Distribution
Tasmania, SW province, locally abundant. Not recorded outside Tasmania.

Conoesucus notialis Jackson
Fig. 24H, I

Conoesucus notialis Jackson, 1998: 138; Jackson 1991: 58.

Holotype
♂ Tasmania, Twin Creeks, Scotts Peak Dam road, 25 Aug. 1988 (NMV).

Diagnosis
Abdominal sternite VII without broad spatulate process; dorsal processes of tergite IX stout, maxilliary palp segment 3 about as long as segments 1 and 2 together (fig. 24I).

Distribution
Tasmania, SW province. Not recorded outside Tasmania.

FAMILY CALOCIDAE

Genus *Caloca* Mosely

Caloca Mosely *in* Mosely & Kimmins, 1953: 153; Neboiss 1977: 90.

Type species
Caloca straminea Mosely, 1953 by original designation.

Caloca tertia Mosely

Caloca tertia Mosely *in* Mosely & Kimmins, 1953: 156; Neboiss 1977: 90.

Holotype
♂ Tasmania, Mt Wellington, Dec. 1937 (BMNH).

Distribution
In addition to the type locality the species is now known from several additional localities thus considerably expanding the known distribution: Louisa Creek, South Coast Track; Adams River; Nelson River at Lyell Highway; Alma Tier, unnamed creek near Lake Sorell; Strathgordon and Hartz Mountains National Park.

Distribution
Tasmania, SE, SW, C and NW provinces. Tasmanian endemic.

FAMILY KOKIRIIDAE

Genus *Taskiria* Neboiss

Taskiria Neboiss, 1977: 80.

Type species
Taskiria austera Neboiss, 1977 by original designation.

Taskiria austera Neboiss

Taskiria austera Neboiss, 1977: 81.

Holotype
♂ Tasmania, West Arthur Plains, 6 Feb. 1965 (NMV).

Additional localities
Tasmania, 1♂ South Coast, Louisa Plains, open buttongrass, 28 Dec. 1978, B.T.; 3♂ Strathgordon, Jan. 1977, J. Sedlacek; 2♂ Swamp near Olga River, 19 km above Gordon River junction, 13 Jan. 1977, A. Neboiss; 1♂ New River Lagoon, buttongrass, 15 Feb. 1988, J. Jackson; 1♂ Franklin River, buttongrass plain, 14 Jan. 1983, ANZSES expedition; 1♂ King William Creek, Site 5A, pitfall, 21 Feb. 2001, M. Driessen; 1♂ King William Creek, Site 5B, sweep, 21 Feb. 2001, M. Driessen. All speciemns in NMV.

Distribution
Tasmania, NW and SW provinces, locally common. Tasmanian endemic.

Taskiria mccubbini Neboiss
Fig. 25A, B

Taskiria mccubbini Neboiss, 1977: 81.

Holotype
♂ Tasmania, Lake Pedder (before flooding), 1 Feb. 1965 (NMV).

Additional localities
Tasmania, 2♂ Lake Pedder impoundment, shore N of Forest Creek, 25 Nov. 1998, J. Jackson, (male gentitalia prep. PT-2141 illustrated), NMV.

Distribution
Tasmania, SW province, rare. Tasmanian endemic.

Genus *Taskiropsyche* Neboiss

Taskiropsyche Neboiss, 1977: 82.

Type species
Taskiropsyche lacustris Neboiss, 1977 by original designation.

Taskiropsyche lacustris Neboiss
Fig. 25C–E

Taskiropsyche lacustris Neboiss, 1977: 82.

Holotype
♂ Tasmania, Lake Pedder (before flooding), 1 Feb. 1965 (NMV).

Additional localities
Tasmania, 1♂ stream, 300 m W of Teds Beach turnoff, 14 Jan. 1999, J. Jackson (male genitalia prep. PT-2198 illustrated), (NMV).

Remarks
The specimen from Teds Beach turnoff has more strongly developed spurs (fig. 25D), and longer hairs on the legs, than specimens in the type series. The genitalia, however, conform fully with those of the type. The type series was collected at the eastern beach of Lake Pedder before flooding.

Distribution
Tasmania, SW province, rare. Tasmanian endemic.

FAMILY ODONTOCERIDAE

Genus *Marilia* Fr. Müller

Marilia Fr. Müller, 1878: 127.

Type species
Marilia major Fr. Müller, 1878 by subsequent designation.

The first record of *Marilia* from Tasmania was that of Kimmins *in* Mosely & Kimmins (1953). He referred to a single male specimen from Deloraine, collected on 28 Dec.1884 under the name *Marilia bola* Mosely, but noted that it is considerably larger, although the male genitalia did not differ from *Marilia bola*. In the absence of any further specimens the genus was neither included nor discussed by Neboiss (1977). Some years later specimens were collected at two localities leaving no doubt that the genus *Marilia* is indeed present in Tasmania. These specimens also proved to be rather large, comparable with that recorded by Kimmins (1953). More recently, over the period 1998–99 larvae were collected at numerous localities by members of the Department of Primary Industries, Water and Environment team. They were examined by Ros St Clair (pers. comm.) and identified as being similar to larvae of *Marilia fusca* Kimmins. They were collected from more than 35 localities; only one is from the west coast, from the Henty River at the Zeehan highway bridge; a few are from the central highlands and northern lowlands, but the majority are from eastern and southeastern districts — Elizabeth, Coal, Bluff, Swan, Scamander, Macquarie and other rivers. These records indicate that the Tasmanian *Marilia* species is associated with larger and slower flowing streams, and, according to collection notes, the larvae inhabit edge water, only seldom the riffle zone.

Separation of species

	bola	*fusca*	*aenigmata*
Forewing length	8–8.5	7.0	10.5–11.6
Female forewing fork 3	present	?	absent
Hind wing fork 1	footstalk	sessile	sessile
Hind wing fork 2	sessile	?	sessile
Hind wing pencil of hair	present	absent	present
Male eyes dorsally	touching	separated by width of eye	touching

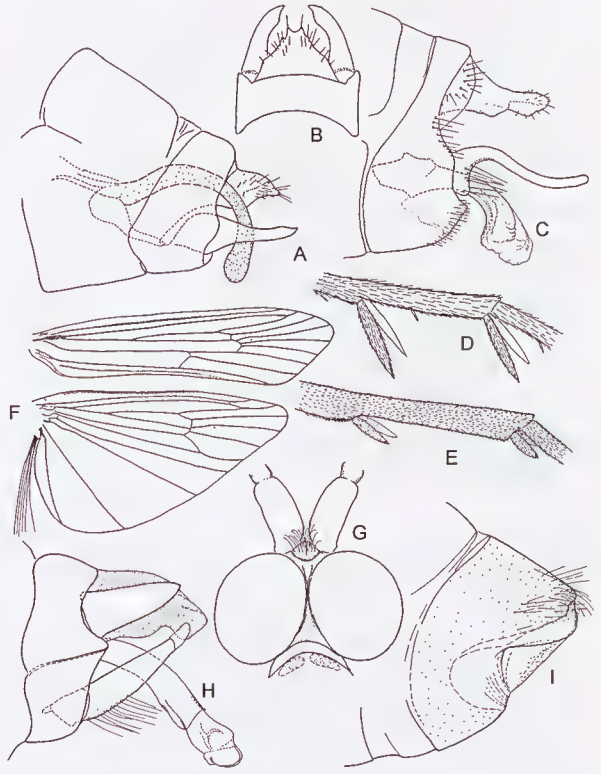

FIG. 25 — (A, B) Taskiria mccubbini *Neboiss, male genitalia: (A) lateral; (B) dorsal. (C–E)* Taskiropsyche lacustris *Neboiss: (C) male genitalia lateral; (D) hind tibia — specimen from Teds Beach; (E) hind tibia — paratype from Lake Pedder east end before flooding. (F–I)* Marilia aenigmata *sp. n.; (F) male wing venation; (G) male head dorsal; (H) male genitalia lateral; (I) female genitalia lateral.*

Marilia aenigmata sp. n.
Fig. 25F–I

Type material
Holotype ♂ Tasmania, Apsley River, 5 km NW of Bicheno, 20 Dec. 1989, J. Jackson. Paratypes 10♂ 10♀ collected with holotype; 5♂ 5♀ 4 km W Orford, 27 Jan. 1983, J. Cardale (wing venation and male genitalia prep. PT-1893, female genitalia prep. PT-1894 illustrated) NMV, ANIC.

Description
Forewing ♂ 9.9–10.8 mm (fig. 25F); ♀ 10.5–11.6 mm; dark reddish-brown with some mottling along the costal margin. Anal lobe of hind wing with pencil of long hair. Forewing forks 1 and 2 long, sessile; fork 3 absent in both sexes; fork 5 long, extending basally to about the middle of discoidal cell; hind wing with forks 1 and 2 long, sessile. In male, eyes large, globose, touching on vertex. Male genitalia (fig. 25H) segment IX with short, somewhat triangular lateral projection; dorsally fused with segment X which terminates with a pair of apically angular lobes; superior appendages large, broad at base, narrowed apically; inferior appendages slender, 2-segmented, apical segment small; phallus slender slightly curved downward.

Female genitalia (fig. 25I) abdominal sternite IX short; tergite IX in dorsal view somewhat triangular, produced distally; terminal segment with deep meso-ventral cleft.

Etymology
Aenigmata (L) — obscure, baffling

Distribution
Tasmania, E, C and NW provinces. Tasmanian endemic.

FAMILY PHILORHEITHRIDAE

Genus *Austrheithrus* Mosely

Austrheithrus Mosely in Mosely & Kimmins, 1953: 190; Neboiss 1977: 177.

Type species
Austrheithrus dubitans Mosely, 1953 by original designation.

Austrheithrus ronewa Mosely

Austrheithrus ronewa Mosely in Mosely & Kimmins, 1953: 192; Neboiss 1977: 117.

Holotype
♂ New South Wales, Mt Kosciuska, alt. 2700 ft, 22 Jan. 1885 (BMNH).

Distribution
Tasmania, widespread; in addition to the northern and eastern records, this species is now recorded from the SW province: Franklin River at Roaring Creek junction and at Gordon River junction; Gordon River nr Smith River junction and above First Split; Sir John Falls; Cataract Creek; and Maxwell-Denison River junction. Other states: Victoria and New South Wales.

Austrheithrus glymma Neboiss

Austrheithrus glymma Neboiss, 1977: 118.

Holotype
♂ Tasmania, St Patricks River nr Targa, 22 Feb. 1971 (NMV).

Distribution
Tasmania: to the previously recorded northern localities two are now added from the SW province — Franklin River-Roaring Creek junction, and Gordon River at First and Second Splits. Other states: Victoria, specimens are now recorded from central and eastern Victoria, where the species appear to be widely distributed and common.

Genus *Tasmanthrus* Mosely

Tasmanthrus Mosely, 1936: 414; Neboiss 1977; 124.

Type species
Tasmanthrus angustipennis Mosely, 1936 by original designation.

The genus *Tasmanthrus* was originally described by Mosely (1936) to include a single species, *Tasmanthrus angustipennis* Mosely from Tasmania. The genus with its only species was discussed again in detail by Mosely & Kimmins (1953). Subsequently, Jacquemart (1965) described another species from the Cradle Mountain area. Numerous specimens from many Tasmanian localities were examined by Neboiss (1977), including the available type material of *T. galbinomaculatus* Jacquemart. He noted some small differences between the two species, but regarded them as insufficient for species separation, particularly considering the poor preservation of the *galbinomaculatus* type and therefore placed it as a junior synonym of *angustipennis*. As more extensive material became available it was recognised that some constant differences exist. Dean and Cartwright (1992) positively recognised the two species from Pelion Valley and suggested that full species status be reinstated for *galbinomaculatus*. St Clair (1997) separated larvae of the two species in her key. More recent field work by Jackson (1998) in the Frenchmans Cap area yielded another closely related species of *Tasmanthrus* which is described in this paper.

Tasmanthrus angustipennis Mosely
Figs 26A, 27A–F

Tasmanthrus angustipennis Mosely, 1936: 414; Mosely & Kimmins 1953: 183; Neboiss 1977: 124.

Holotype
♂ Tasmania, Miena, Great Lake, Dec. 1930 (BMNH).

Diagnosis
Compared with the other two species the wings are distinctly more slender (fig. 26A); in male genitalia segment X has distinctly elevated or humped meso-dorsal section; inferior appendages have the upper branch not distinctly widened at base; abdominal sternites VI and VII usually without or with very small meso-ventral protuberances.

Distribution
Tasmania widespread and common. Not recorded from other states.

Tasmanthrus galbinomaculatus Jacquemart
Figs 26B, 27G–I

Tasmanthrus galbinomaculatus Jacquemart 1965: 19; Dean and Cartwright 1992: 75.
Tasmanthrus angustipennis. Neboiss 1977: 124.

Holotype
♂ Tasmania, Cradle Mountain, 12 Jan. 1923 (IRScNB).

Additional material examined
Tasmania 2♂ and 2♂ pupae (fully developed), unnamed Creek, Overland Track approx. 250 m E of Frog Flats, Cradle Mountain-Lake St Clair National Park, 18 Jan 1990, J. Dean and D. Cartwright (male genitalia prep. PT-1830 illustrated); 1♂ Mt Field National Park, alt. 200 m, 4 Feb. 1980, A. Newton and M. Thayer; 1♂ Little Florentine River, Southwest National Park, 22 Jan. 1976, A. Wells.

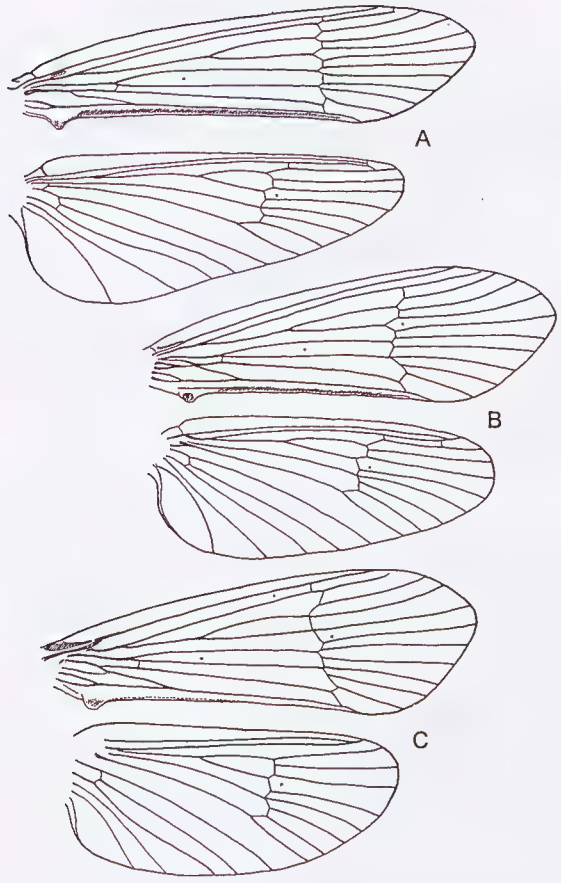

FIG. 26 — Tasmanthrus *spp., male wing venation: (A)* T. angustipennis *Mosely; (B)* T. galbinomaculatus *Jacquemart; (C)* T. gwendolensis *sp. n.*

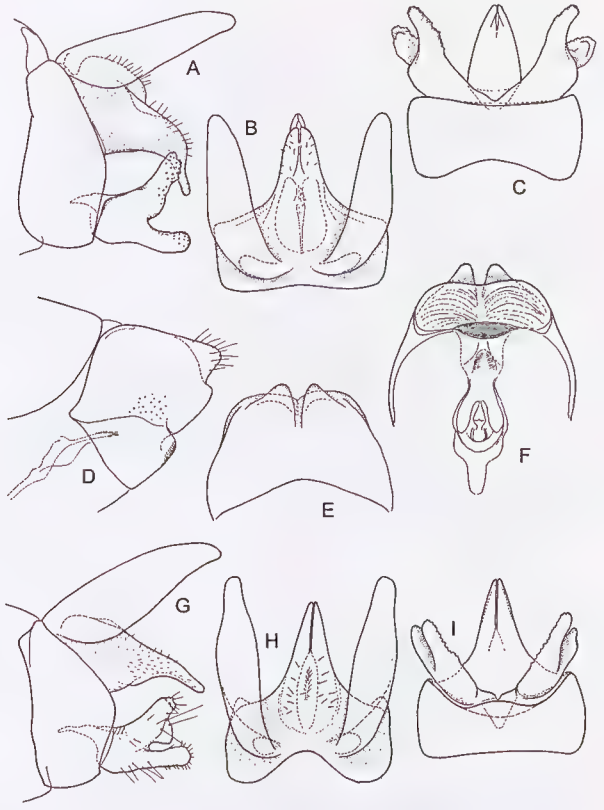

FIG. 27 — (A–F) Tasmanthrus angustipennis *Mosely. (A–C) male genitalia: (A) lateral; (B) dorsal; (C) ventral. (D–F) female genitalia: (D) lateral; (E) dorsal; (F) ventral. (G–I)* Tasmanthrus galbinomaculatus *Jacquemart, male genitalia: (G) lateral; (H) dorsal; (I) ventral.*

Diagnosis

Wings proportionally broader than in *angustipennis* (fig. 26B) apex of hindwing broadly rounded. Male maxillary palpi with terminal segment elongate and tapering apically; male genitalia (fig. 27G–I) segment X meso-dorsally at most only slightly with elevated longitudinal ridge; in lateral view gradually tapering distally, only slightly curved downwards; inferior appendages upper branch distinctly widened near base; abdominal sternites VI and VII with distinct apically pointed processes.

Distribution

Tasmania. Tasmanian endemic.

Tasmanthrus gwendolensis sp. n.
Figs 26C, 28A–D

Holotype

♂ Tasmania, Lake Gwendolen, Frenchmans Cap area, sweep net, 28 Jan. 1988, J. Jackson. Paratypes 3♂ 1♀, collected with holotype (male genitalia preps PT-1697 and female PT-1881 illustrated), NMV.

Description

Adults dark blackish-brown, forewings with small pale greyish irregular spots. Length of forewing ♂ 7.4–8.6 mm; ♀ 10.8 mm. Male genitalia (fig. 28A, B) superior appendages large, elongate ovoid, apically rounded; segment X broad at base, tapering distally, apex with V-shaped mesal cleft, each side ending with a somewhat rounded knob; inferior appendages robust, two branched, the upper branch robust, expanded at base; abdominal sternites VI and VII with small, pointed meso-ventral processes. Phallus curved downwards.

Female abdomen (fig. 28C, D) terminates bluntly; dorsally distal end developed into two apically somewhat triangular lobes, mesally separated by comparatively broad elongate gap, which has a distinct mesal midline or ridge.

Etymology

Named after the type locality, Lake Gwendolen.

Distribution

Tasmania, known only from type locality, SW province. Tasmanian endemic.

FAMILY LEPTOCERIDAE

Genus *Leptorussa* Mosely

Leptorussa Mosely *in* Mosely & Kimmins, 1953: 272; Neboiss 1977: 141.

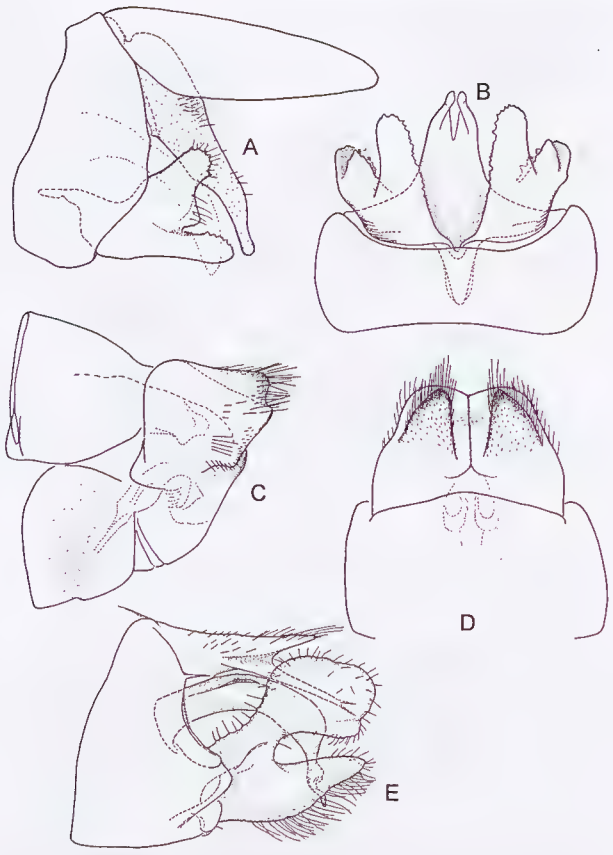

FIG. 28 — (A–D) Tasmanthrus gwendolensis *sp. n. (A, B) male genitalia: (A) lateral; (B) ventral. (C, D) female genitalia: (C) lateral; (D) dorsal. (E)* Leptocerus souta *Mosely, male genitalia lateral.*

Type species
Leptorussa russata Mosely, 1953 by original designation.

Leptorussa darlingtoni (Banks)

Leptocerus darlingtoni Banks, 1939; 487; Neboiss 1977: 141.
Leptorussa russata Mosely *in* Mosely & Kimmins 1953: 274.

Holotype
♂ South Australia, Mt Lofty Ranges, 29 Nov. 1931 (ANIC).

Distribution
Tasmania widespread; in addition to previously recorded localities the following are now added: Lake Pedder, several shore locations; Maria Creek and Sandfly Creek; Franklin River at Roaring Creek junction; Wilson Creek nr Hellyer; Rubicon River nr Sassafras; Mt Field National Park. Other states: Victoria, South Australia, New South Wales.

Genus *Leptocerus* Leach

Leptocerus Leach, 1815: 136.

Type species
Phryganea interrupta Fabricius, 1775 by monotypy.

Leptocerus souta Mosely (Fig. 28E)

Leptocerus souta Mosely *in* Mosely & Kimmins, 1953: 278; Neboiss 1986: 255; Schmid 1987: 126.

Holotype
♂ South Australia (without locality or date) (BMNH).

The species was first recorded from Tasmania and identified positively by Neboiss in 1991, but no further adult specimens have been collected. Larvae, recorded by Ros St Clair (pers. comm.) as probably this species, were collected from the Sorell area and published by Jackson 1999.

Material examined
Tasmania, 2♂ Macquarie River, 18 Dec. 1990, S. Chilcott; larvae, Sorell Rivulet, Pawleena Reservoir nr Sorell, 42°43'S, 147°35'E (no date given), NMV voucher specimen AV 5562. All material in NMV.

Distribution
Tasmania, N and SE provinces. Other states: South Australia, Victoria, New South Wales, Queensland.

Genus *Lectrides* Mosely

Lectrides Mosely *in* Mosely & Kimmins, 1953: 270; Neboiss 1977: 135.

Type species
Lectrides varians Mosely, 1953 by original designation.

Lectrides varians Mosely

Lectrides varians Mosely *in* Mosely & Kimmins, 1953: 270, Neboiss 1977: 135.

Holotype
♂ Tasmania, Sheffield, 8 Jan. 1917 (BMNH).

Distribution
Tasmania, widely distributed throughout the state. Recently recorded from the following areas: Lake Tahune, Frenchmans Cap area; Mulcahy Bay, Lake Pedder several shore localities; Strathgordon; Sir John Falls; Olga River; South Esk River near Evandale; Hellyer River Gorge; Great Forester River; Apsley River near Bicheno; Russell Falls. Other states: South Australia, Victoria, New South Wales, southeast Queensland.

ACKNOWLEDGEMENTS

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(accepted 29 July 2002)

DAY USE OF NEST SITES BY THE TASMANIAN BETTONG (*BETTONGIA GAIMARDI*)

by M. Statham and H. L. Statham

(with two tables and two text-figures)

STATHAM, M. & STATHAM, H.L., 2002 (31:xii): Day use of nest sites by the Tasmanian bettong (*Bettongia gaimardi*). *Papers and Proceedings of the Royal Society of Tasmania* 136: 83–88. ISSN 0080–4703. Tasmanian Institute of Agricultural Research, Mount Pleasant Laboratories, PO Box 46, Kings Meadows, Tasmania 7249, Australia.

A bettong (*Bettongia gaimardi*) population in the Tom Gibson Reserve, northern Tasmania, was studied for 16 months by trapping and radio-tracking as part of a long-term study of fencing for control of wallabies and the effect on non-target species. Of particular interest was the bettongs' usage of retained bush areas in cultivated paddocks, and the distribution of nest sites. Sixteen of the 26 bettongs trapped were radio-tracked weekly to their daytime nest sites for intervals of nine to 57 weeks. Bettongs occupied between six and 43 different nests; in all, 305 different nests were located. On 23% of occasions, adult females shared nest sites with furred young at heel; however, adults rarely shared a nest. Breeding apparently occurred at any time of the year and all adult females had a pouch young every time they were examined.

Estimates based on minimum convex polygon position of nest sites averaged 14.5 ha for females and 27.7 ha for males. All nest sites were accessible from low understorey corridors; bettongs did not appear to cross open pasture to access apparently similar habitat to that being used. One young male travelled along a bushland corridor for over 4 km before radio contact was lost.

Key Words: Bettong nest, *Bettongia gaimardi.*

INTRODUCTION

The Tasmanian bettong (*Bettongia gaimardi*), a member of the Potoroidae, was once widespread in southeastern Australia, but now occurs only in Tasmania. Although it is found over much of eastern Tasmania in a wide range of dry sclerophyll forest types, it is most abundant in areas with infertile soils, open undergrowth and extensive mycorrhizal root development (Taylor 1993a). It is strictly nocturnal and rests through the day in a nest of grass and bark (Kershaw 1952, Rose 1986, Taylor 1993b). No long-term studies of the use of nest sites by individual bettongs have previously been carried out.

METHODS

The Study Area

The study was carried out at the Tom Gibson Reserve (41°46'S, 147°19'E), which is 2.5 km southwest of Epping Forest in the northern midlands of Tasmania. The study area consists of gently undulating quaternary flats of lateritic gravel, sand and clay. There is a ridge of stony dolerite hills on the southwestern margin, and dolerite outcrops of low hills in the north and west, both in the reserve and on private land outside the reserve. Dry sclerophyll forests and woodland dominated by *Eucalyptus amygdalina* are the predominant vegetation types. *Acacia dealbata* regrowth, clumps of *Banksia marginata*, and several large patches of *Spyridium vexilliferum* are the main shrub species. Heath species such as *Hibbertia* spp., *Leucopogon collinus, L. virgatus* and *Lissanthe strigosa* dominate the undisturbed lateritic areas, although past excavation for gravel has left much of the lateritic ground bare or slowly regenerating. There are patches of dense bracken (*Pteridiun esculentum*) on sandy soils. Tussocks of *Lomandra longifolia* and *Lepidosperma longitudinale* dominate the wide, shallow gullies. Private land to the northeast and east of the reserve has been cleared for grazing and cropping, with some corridors and patches of natural bush retained (see fig. 1).

Trapping

Bettongs were live-trapped with Mascot treadle traps, 600 x 300 x 300 mm in size, during ten trapping periods of four nights each, over 16 months between July 1997 and October 1998. Trapping was concentrated along a bush and pasture interface to maximise capture of individuals whose nesting ranges might include patches of remnant forest isolated by pasture. At each trapping, about 50 traps were set in three rows parallel to a fire trail on the northeastern boundary of the reserve. The first row of 18 traps was placed next to a fire trail, on the reserve side, with a trap spacing of 100 m (see fig. 1). The first eight of these traps ran between the track and cleared pasture, while the remaining ten trap sites were adjacent to uncleared private land bordering the reserve. Some of the uncleared land was in a narrow strip. The next two rows were 50 m and 100 m, respectively, further into the reserve. For the first trapping period, the traps were baited with apple following Statham's (1983) method; subsequently, peanut butter was smeared onto the apple and trap treadle. The traps were thoroughly washed with a steam cleaner after each trapping period.

On first capture, each animal was removed from the trap, bagged, weighed and anaesthetised with zoletil (3 mg kg^{-1} intramuscular) before an electronic chip (Trovan) was implanted just under the skin between the shoulder blades. The females' pouches were checked and any pouch young measured, with care being taken not to remove them from the nipple, as mothers abandon pouch young if they are separated. Most bettongs weighing at least 1 kg were fitted with individually identifiable radio collars (Sirtrack, Havelock North, New Zealand, weight 44 g each).

FIG. 1 — Trap and nest sites.

At subsequent capture, individuals were identified, collars were checked, body weights recorded and pouch young measured. Radio collars were removed at the end of the study and the animals released *in situ.*

Radio Tracking

Radio-collared bettongs were located at their nest sites during the day, usually once a week, for 57 weeks. Tracking was generally done by two people on foot using a hand-held, three-element Yagi aerial. Each animal was located and its nest site described and marked by a numbered tape. The nest's location was recorded with a GPS receiver. Sixteen different bettongs (six females and ten males) were radio-tracked for intervals ranging from nine to 57 weeks (table 1).

Mapping

A GPS receiver (Trimble GeoExplorer II®) was used to map tracks, fences and other features, which were then plotted with bettong trapping and radio-tracking data on a digitised 1:25000 scale base map, using Arcview software. Nest-range sizes were calculated as minimum convex polygons, i.e., the minimum area that included all recorded nests.

RESULTS

Trapping

A total of 26 bettongs — 18 males and eight females — were captured. There were 76 male captures and recaptures, ranging from one to 11 per individual, and 40 female captures and recaptures, ranging from one to 12 per individual. The total number of trapping nights was 1380, with a trapping success rate of 8.4%. No bettongs were captured during the first trapping period, when only apple was used as bait, but at least one animal was captured in all subsequent trapping periods when peanut butter was added to both the bait and the trap treadle plate. They usually ate all the peanut butter and rarely touched the apple.

Other species were occasionally captured: Tasmanian devil (*Sarcophilis harrisii*); spotted-tail quoll (*Dasyurus maculatus*), Tasmanian pademelon (*Thylogale billardierii*) and black currawong (*Strepera fuliginosa*). Common brushtail possums (*Trichosurus vulpecula*) were captured far more frequently than bettongs, with up to 28 a night, while the highest number of bettongs caught in a night was six. (None of the possums was identified or weighed.) The effect of the high trapping rate of possums on numbers of bettongs trapped is unknown. Bettongs were active at night earlier than possums and therefore had access to the traps, but later in the night the number of traps occupied by possums would have reduced those available to bettongs.

Weights of independently trapped bettongs ranged from 0.9 to 2.2 kg. Most independent males weighed between 1.6 and 2.0 kg. All independent females weighed between 1.6 and 2.3 kg, with some weight, particularly for the heavier ones, attributable to pouch young. It was not possible to accurately record the weight of lactating females because the young, unless fully furred, were usually attached to a nipple.

Nest Sites

In all, 305 different nests were located. Most were recorded as being used by one bettong on one occasion. Individuals returned to a nest they had previously used on 11% of occasions and used a nest previously used by a different bettong on 4% of occasions. Individual nests were rarely found to be used more than twice during the study, although one nest was recorded as used on five occasions. The time interval between recorded use of a particular nest varied between one week and 10 months, with two to three months being the most usual. Individuals used between six and 43 different nests during the study. Concurrent use of nests occurred mainly when furred young were still accompanying their mothers.

The six adult females radio-tracked to their nests were accompanied by a furred young at heel on an average of 23% of occasions (range 0–44% between individual females). If flushed out of the nest, the adult female always left the nest several seconds before her young, which hopped off in a completely different direction. On five occasions, two adult bettongs left a single nest, and on one of these a young at heel also emerged. Only one of the two adults was radio-collared on each occasion and hence the sex of the uncollared one is unknown.

The nests were always on the ground and usually in a slight depression. They mostly consisted of a small tunnel of grass, bark or other nesting material built under fallen limbs and litter, in tussocks of *Lomandra longifolia* or *Lepidosperma longitudinale*, under very low shrubs such as *Hibbertia* spp. and *Leucopogon* spp. or a combination of these conditions. Each nest was very well camouflaged and was found only when the observer was within one to two metres of the bettong being radio-tracked.

All the nest sites were in dry sclerophyll forest or woodland with undisturbed understorey, within the main block of uncleared land, either in the Tom Gibson Reserve or immediately adjacent in private property. The only evidence of movements out of this area were nest sites found in strips of undisturbed forest. An exception was a nest located across the road, used by a male, which could have been accessed by travelling in undisturbed forest or along a shelter-belt except when actually crossing the road (fig. 1). No nest sites or evidence of digging was found in islands of apparently similar remnant forest separated by cleared land, even though the distance was less than 30 metres. For several months during the tracking period the cleared land was fallow, with a soft, friable surface, but no bettong footprints were found on the strip next to the fire trail.

Nesting Range Estimates and Movement

The nest ranges, or area covered by daytime nesting sites, were calculated from those individuals for which the estimates of maximum nesting range appeared to have been reached (additional data did not increase the nest range) (table 1). These averaged 14.5 ± 9.2 ha for females and 27.7 ± 20.4 for males.

The ranges of individual females rarely overlapped at a particular point in time, and the nests of each female were closer together than the males' nests. However, when a female died, another would establish in her area. For example, after female number 1 died, number 24 was trapped and tracked in her former range. Male 3 occupied a larger range, overlapping those of both females, throughout the entire study (fig. 2).

The smaller range size for females is also illustrated by figure 2, which shows overlapping trap sites and nest sites of four bettongs (males 5, 7 and 11, and female 17). These four bettongs all moved outside the reserve but stayed within the one block of undisturbed habitat. They spent most of their time outside the reserve, but were readily captured in traps located in the reserve outside their known nesting range.

Only two individuals regularly nested away from the core forest block. These individuals, mother and son (4 and 14) moved along the 40–50 m-wide bush corridor retained to the northeast of the reserve and adjacent to the road (fig. 1). Female number 4 was found dead in an island of bush surrounded by paddock. This was the only time an animal was tracked in a location that required it to cross bare paddock. Soon after, the young male dispersed via bush corridors and was last located 4.5 km from his earlier nest sites (fig. 1).

Breeding

Information on bettong breeding was obtained from both tracking and trapping data (table 2). Breeding apparently occurred at any time of the year; all adult females had a pouch young every time they were examined. Individuals often had a small pouch young and another fully furred young at heel. The latter were occasionally trapped with their mother, but were more often flushed out of the nest during day tracking.

DISCUSSION

Previous studies on the movement of the Tasmanian bettong have indicated home ranges of 50.1 ± 10.5 ha for females and 65.3 ± 19.0 for males (Taylor 1993a) and approximately 100 ha for males (Johnson 1978, Mooney & Johnson 1979). As these studies included day nest sites and night tracking data, the ranges are greater than in our study, which was restricted to nesting ranges.

In general, the bettongs were trapped near their nest home ranges. Bettongs 5, 7, 11 and 17 were atypical in that they were trapped at a distance from their known nest ranges (fig. 2). These bettongs conform with a report that bettongs may travel up to 2 km to and from known feeding areas in a given night (Mooney & Johnson 1979). This was emphasised by the fact that we were unable to trap these

TABLE 1

Radio-tracking data: number of times captured, number of weeks tracked, total number of radio fixes, number of different nests, number of fixes to achieve maximum nesting range, and fate of 16 bettongs radio tracked. The mean nest range for males was 27.7± 20.4, and for females 14.5 ± 9.2 ha.

No.	Sex	Captures (*n*)	Weeks tracked (*n*)	Radio fixes*	Diff. nests (*n*)	Fixes for max. nest range (*n*)	Nest range (ha)	Fate
1	F	10	47	35	31	31	14	Eaten, skeleton found near collar
2	F	12	57	43	38	39	12	Released at end of study
3	M	11	57	43	36	31	29	Released at end of study
4	F	8	49	36	29	25	27	Found dead, suspect Tiger Quoll
5	M	1	27	24	20	14	20	Lost signal February 98
7	M	9	56	30	28	25	22	Released at end of study
8	M	7	31	23	18	22	72	Lost signal March 98
9	M	6	56	34	32	32	23	Released at end of study
10	M	4	25	10	10	9	9	Collar recovered, no bettong, March 98
11	M	7	56	28	18	23	19	Released at end of study
16	M	7	28	13	7	13	–	Released at end of study
17	F	4	20	16	15	11	5	Released at end of study
19	M	3	9	6	6	6	–	Lost signal June 98
21	F	1	20	13	13	13	–	Released at end of study
23	M	4	14	10	8	10	–	Lost signal September 98
24	F	3	11	9	9	9	–	Released at end of study

* Equates to the total number of nests found.

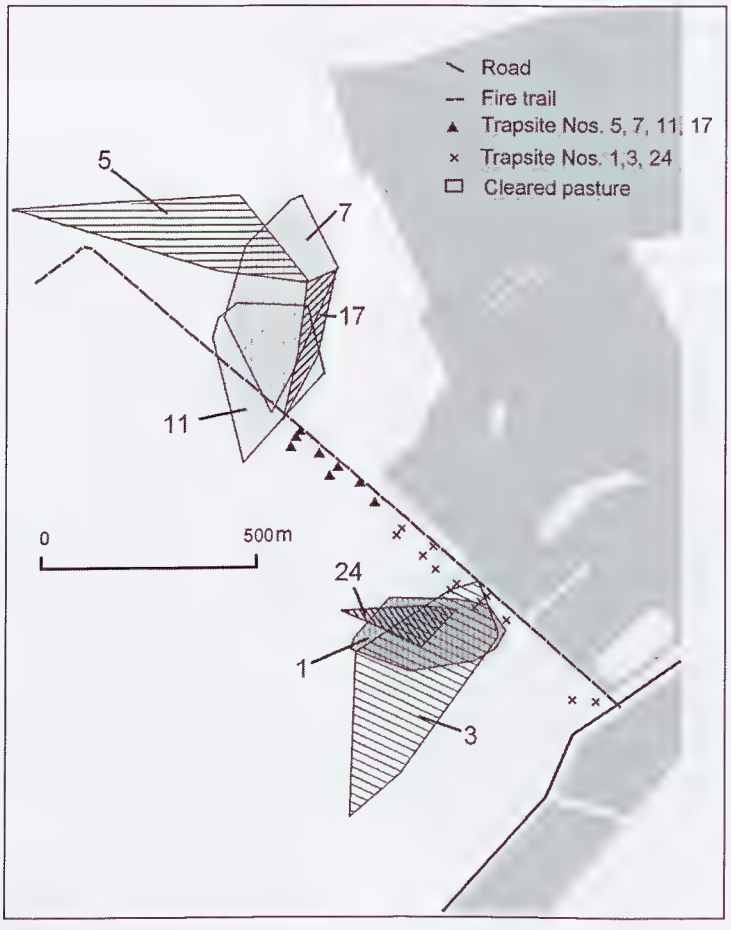

FIG. 2 — Nest range and trap sites of bettongs 1, 3, 5, 7, 11, 17 and 24.

TABLE 2
Bettong breeding: female bettongs captured during the study and details of small pouch young and furred young at heel from trapping and tracking data

Female no.	Date	Pouch young h+b (mm)†	Furred young trapped with mother or flushed out of nest when mother was tracked
1	Aug 97	20	
*	Aug–Sept 97		One (unidentified) flushed out several times; presumably male # 6, which was never collared.
*	Nov 97–Jan 98		One (unidentified) flushed out, too small to be #6.
	Dec 97	50	
	Apr 98	50	
*	Apr–June 98		Male 22† flushed out with mother.
2	Aug 97	60	
	Dec 97	+	Furless, not measured.
*	Late Jan–Mar 98		Female 15† flushed out with mother.
	Feb 98	15	Female 15† and small pouch young trapped with mother.
	Mar 98	70	
*	May–early Jun 98		Furred young flushed out with mother.
	May 98	20	
*	Aug 98–Sept 98		Furred young flushed out with mother.
	Oct 98	20	
4	Aug 97	90	
*	Dec 97		Male 12† trapped with mother.
	Feb 98	50	
	Apr 98	20	
*	Apr–Jun 98		Male 23† flushed out with mother.
	May 98	80	Male 23† (1.06 kg) trapped with mother and small pouch young.
17*	Apr 98		Female 18† (0.25 kg) trapped with mother.
	May 98	50	
	July 98	20	
*	Aug–Oct 98		Female 18† flushed out with mother.
	Oct 98	+	
21	May 98	50	
*	Aug–Sept 98		Furred young flushed out with mother.
	Oct 98	50	
24	July 98	+	Female (0.65 kg) died in captivity.
	Oct 98	50	

† Length of head and body in millimetres.
* Observations from radio-tracking; pouch not examined (even if trapped).

four bettongs in their known nesting ranges when trying to replace collars transmitting weak signals. Our data conform with those for other Macropodoidea, in that males had larger home ranges than females (Croft 1989).

Reproduction in this population was similar to that described in a captive population (Rose 1982), with births in all months of the year. After a pouch life of 105 days, the young is replaced by a foetus conceived at a previous post-partum mating (Rose 1982). This allows more than one young to be raised each year.

The use of the 40–50 m-wide bush corridor by two individuals indicates the importance of retaining such strips of natural vegetation for native animals such as the bettong. These corridors reduce the chance of predation when young are dispersing, and allow interaction between otherwise isolated populations, enhancing the genetic variability necessary for long-term species viability.

These data are important to consider when planning wallaby exclusion fencing to minimise effects on other species. Placement of fence lines along pasture and bush interfaces should have little effect on bettong movement, providing "corridor" areas are not closed off. Maintenance of access through bush corridors, and the development of suitably vegetated corridors between areas of remnant forest, will assist in the dispersal of bettongs and maintenance of populations.

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(accepted 29 July 2002)

A PRELIMINARY CENSUS OF THE MACROFUNGI OF MOUNT WELLINGTON, TASMANIA – THE AGARICALES

by David A. Ratkowsky and Genevieve M. Gates

(with three tables, one text-figure and one appendix)

RATKOWSKY, D.A. & GATES, G.M., 2002 (31:xii): A preliminary census of the macrofungi of Mount Wellington, Tasmania – the Agaricales. *Papers and Proceedings of the Royal Society of Tasmania* 136: 89–100. ISSN 0080-4703. School of Plant Science, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia.

The macrofungi of Tasmania are part of a kingdom of living organisms that is poorly known in Australia; most species are unnamed and undescribed. The present work represents an initial attempt at identifying the rich mycobiota of Mount Wellington, one of Tasmania's best-known and most-studied regions for other plant groups. Attention is confined to the 'gilled' fungi, the order Agaricales. The agarics of Mount Wellington comprise a very large group, and in the 15 families recognised, 130 previously named and described species are differentiated and presented here. The true number of species is at least twice that many, as some large families have been inadequately studied in Australia. For example, in the family Entolomataceae, we believe there are over 50 distinct species in the genus *Entoloma* and at least four species in the genus *Rhodocybe* on Mount Wellington.

Key Words: Macrofungi, Agaricales, agarics, Mount Wellington (Tasmania).

INTRODUCTION

One of the authors (DAR) has previously been involved in surveys of the phanerogams (Ratkowsky & Ratkowsky 1976, 1977), bryophytes (Ratkowsky & Ratkowsky 1982) and lichens (Ratkowsky *et al.* 1989) of the Wellington Range, near Hobart, Tasmania. This study extends the series of surveys to the order Agaricales of the Kingdom Fungi. Mycologists are not in agreement as to the total number of macrofungal species in Australia, but they do agree that the number of currently named and described species represents only a small percentage of the actual number of species present on the Australian continent. There are few professional taxonomic mycologists in Australia, and revisions of fungal families and/or genera have been slow to appear. Most active Australian mycologists are involved in plant pathology, crop and forest protection, and other activities that offer little or no time for taxonomy. There is, however, much scope for taxonomic work, and revisions of most families and some genera are needed.

The boundaries of the order Agaricales are a subject of disagreement amongst mycologists. Recent work with ribosomal DNA in fungal genes is resulting in major changes in phylogenetic concepts about which families should be placed within, or omitted from, the Agaricales. Some of the changes resulting from this and other recent research are reflected in the ninth edition of the *Dictionary of the Fungi* (Kirk *et al.* 2001), which broadens the concept of Agaricales in some respects and narrows it in others. The authors have chosen to follow the classification scheme for genera within families adopted by Bougher & Syme (1998), except for some minor disagreements as to the placement of some genera. Interested readers wishing to identify gilled fungi seen in the field to the level of genus should consult the present authors' recently published keys to the families and genera of agarics in Tasmania (Ratkowsky & Gates 2002).

MATERIALS AND METHODS

Survey Zones

Mount Wellington, which rises to 1270 m, lies west of Hobart, at 42°54'S, 147°14'E (see fig. 1 for a general location map). As the mycobiota of the mountain is greatly reduced in many of the ecological zones in comparison to flowering plants, bryophytes or lichens, the macrofungal survey covered a much smaller area than the previous surveys mentioned in the Introduction. The most frequently visited localities on Mount Wellington were the wet, eastern-facing gullies. The main tracks we used on the east face (42°55'S, 147°15'E) at elevations between 350 and 720 m (see the Mount Wellington Walk Map and Notes, Department of Environment and Land Management, Tasmania, 1997, for the track routes) were Fern Glade, Middle, Reids, Pipeline, Jacksons, Betts Vale, Circle, Shoobridge, Lenah Valley, Radfords, Sphinx Rock and Silver Falls. Slightly further to the north (42°54'S, 147°15'E; elev. 300–580 m) we used Myrtle Gully and Old Farm Trail. The other frequently used tracks were Myrtle Forest Creek above Collinsvale (42°52'S, 147°09'E; elev. 600 m), Truganini (42°56'S, 147°21'E; elev. 100–340 m), various trails around the Waterworks Reserve Reservoirs (42°54'S, 147°17'E; elev. 200 m), and the portion of the track to Cathedral Rock that follows alongside the North West Bay River (42°57'S, 147°12'E; 250 m). We also made limited use of several other tracks.

A factor limiting the size of the survey area in comparison to the earlier plant surveys was the extent of vegetation recovery since the 1967 bushfires, making cross-country travel at lower elevations difficult. Following the approach taken by Ratkowsky & Ratkowsky (1976, 1977), the habitat of the Mount Wellington survey area was divided up into zones determined largely by the dominant species of *Eucalyptus* present. The zones ranged from lowland areas up to 400–500 m elevation of dry sclerophyll on either dolerite or mudstone, to treeless montane shrubberies and grasslands above 1220 m. Very few macrofungi were found

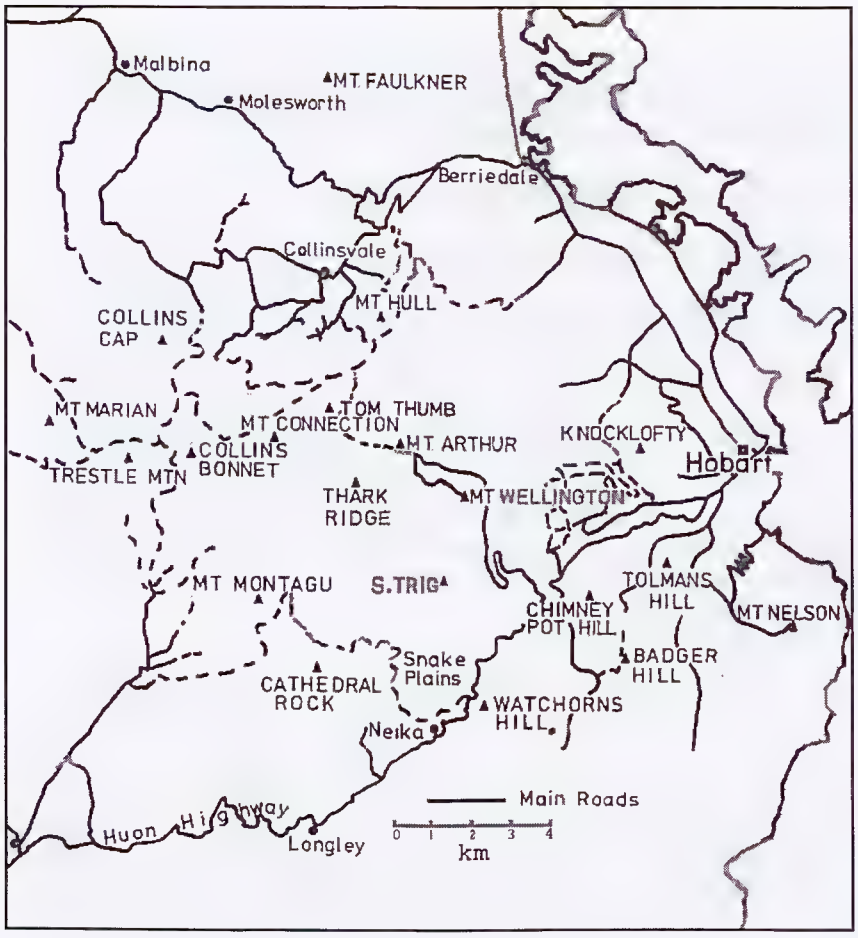

FIG. 1 – Location map of Mount Wellington, showing some of its features.

at elevations corresponding to the treeless uppermost zone or the zone containing *Eucalyptus coccifera* as the sole eucalypt species, and few were also found in the zone dominated by *E. urnigera.* Owing to the scarcity of agarics at the higher altitudes, the Milles, Pinnacle and Ice House Tracks were rarely used.

The most productive zones mycologically were (1) 'gully communities' (up to 600 m elevation), which are permanently wet and with a thick undergrowth lacking *Eucalyptus* spp. (except for the steep sides of the gullies, which might support *E. regnans* in well-drained pockets), but which often contains *Nothofagus cunninghamii* (Fagaceae), *Bedfordia salicina* and *Olearia argophylla* (both Asteraceae), *Pomaderris apetala* (Rhamnaceae) and *Prosanthera lasianthos* (Lamiaceae), (2) 'wet sclerophyll forest' (up to 670 m) on either Permian or dolerite deposits, the former with *Eucalyptus obliqua* as the dominant eucalypt species, and the latter, at higher elevations (600–800 m), dominated by *E. delegatensis.* Other tree or shrub species in the wet sclerophyll include those of the gully communities mentioned above, plus the myrtaceous shrubs *Leptospermum scoparium* and *L. lanigerum,* the wattles *Acacia verniciflua* and *A. dealbata* (Mimosaceae), *Pultenaea juniperina* (Fabaceae), *Olearia phlogopappa* and *O. viscosa* (Asteraceae), as well as *Oxylobium ellipticum* (Fabaceae). Few fungi appeared in the dry sclerophyll habitat at lower elevations (up to 500 m) dominated by *Eucalyptus viminalis* and *E. pulchella* on dolerite, except for certain wet gullies within these basically dry environments, such as the Truganini Track in the Cartwright Creek gully below Mount Nelson. Also productive was the track up Myrtle Forest Creek, which is at an elevation of about 600 m and wet enough to sustain a large component of rainforest species.

The fieldwork for the project began in January 1994 and is continuing at the time of writing. It is part of a wider program of fungal surveys in southeastern Tasmania. During the first four years of the project, Mount Wellington was visited almost daily (by A. V. Ratkowsky), but between mid-1998 and mid-1999, the authors visited Mount Wellington once or twice a week, and from then to the present time much less frequently, with the emphasis shifting to sites in other parts of Tasmania. Throughout the survey, visits were made in each of the twelve months of the year.

Ecological Comparisons

The survey was not designed for conducting ecological comparisons, such as between wet and dry sclerophyll sites, between low-altitude and high-altitude sites, or between geological substrates such as sandstone, mudstone and dolerite. However, there is some scope for making comparisons within some sites grouped under the broad headings of wet sclerophyll forests and wet gully communities. The most promising comparison is between Myrtle Gully, a wet gully community, and Old Farm Trail, a fairly open wet sclerophyll environment subject to drying out during periods of low rainfall. These tracks were almost always visited on the same day, usually Myrtle Gully in ascent, followed by Old Farm Trail in descent, enabling a comparison

to be made with a paired-sample t-test and its nonparametric equivalent, the Wilcoxon signed-rank test.

A less satisfactory comparison can also be made between Myrtle Gully and other wet gullies visited no more than 16 days apart. Because the time span prevents this comparison from being viewed as a paired comparison, a two-sample t-test for independent samples and the nonparametric Wilcoxon–Mann–Whitney and Median tests were used. These tests are included in this paper, at a referee's suggestion, to illustrate some of the possibilities for making ecological comparisons in surveys specifically designed for that purpose. The principal purpose of this paper was to obtain preliminary data on which species of macrofungi were present on Mount Wellington.

RESULTS

Although about 260 distinct species of agarics were differentiated from the material collected from Mount Wellington, only 130 of these have been validly named and described. The latter species are the ones presented here (see appendix), with the author or authors cited in the usual way. The nomenclature follows May & Wood (1997), as updated by the interactive catalogue of fungi on the website of the Royal Botanic Gardens Melbourne (www.rbg.vic.gov.au). Wherever possible, references are given to published photographs and illustrations in readily available sources. Where the illustration is only of microscopic characters, this is explicitly stated. Voucher material of each of the species listed in the Appendix is deposited in the Tasmanian Herbarium (HO). In addition, wherever there is sufficient material available, voucher specimens are also placed in the National Herbarium of Victoria (MEL).

Table 1 lists the total number of fungi species, from all orders and families, found in Myrtle Gully and Old Farm Trail, the visits to both sites being made on the same day. Since the number of species on each of the 20 visits was greater at Myrtle Gully than at Old Farm Trail, it is clear that Myrtle Gully is significantly richer, even when a test of low power, such as the Sign test ($p < 0.0001$), is used. The more powerful Wilcoxon signed-rank test and the paired-comparison t-test give similarly low P-values ($p < 0.0001$). As Myrtle Gully resists drying out to a greater extent than Old Farm Trail, this result is not surprising. A contributory factor to the large difference between sites could be that Myrtle Gully was almost always surveyed in ascent, and Old Farm Trail in descent, and species are more easily seen during the slower pace of ascent. However, this factor is not deemed to be of primary importance.

Seasonal effects are readily apparent from examination of the data entries for any given year, but there is considerable variability from year to year. For example, the early months of 2000 and 2001 were rather dry, leading to a late start to the fungi 'season', whereas in 2002, early rains brought about good numbers in February, followed by a decline in May, when numbers are normally high, owing to a dry March and April. On average over a period of more than three years, the summer months (Dec.–Feb.) produced only 34.8 species in Myrtle Gully, compared with 52.1 in autumn (Mar.–May), 53.3 for winter (Jun.–Aug.) and 52.5 for spring (Sep.–Nov.). Similarly, for Old Farm Trail, the average number of species was lower in summer than in any other season.

Visually, it appeared that, despite the lower total number of species, there were more species of *Cortinarius* and *Russula* as a proportion of the total mycobiota along Old Farm Trail than along Myrtle Gully. Table 2 gives the number of species of each of these two genera at the two sites. For *Cortinarius*, there is no difference between the

TABLE 1
Comparison of total number of species at Myrtle Gully and Old Farm Trail

Date	Myrtle Gully	Old Farm Trail	Difference
09 Mar 99	72	23	49
13 Apr 99	73	7	66
15 Jun 99	59	19	40
06 Sep 99	37	10	27
10 Feb 00	4	0	4
21 Mar 00	28	5	23
18 May 00	54	4	50
22 Jun 00	46	32	14
09 Nov 00	60	19	41
12 Dec 00	27	4	23
09 Jan 01	17	2	15
06 Mar 01	7	0	7
03 May 01	102	18	84
28 Jun 01	45	4	41
31 Jul 01	63	15	48
15 Sep 01	59	8	51
27 Nov 01	54	13	41
17 Jan 02	67	21	46
21 Feb 02	59	6	53
07 May 02	29	2	27
Mean	48.1	10.6	37.5

TABLE 2
Comparison of *Cortinarius* and *Russula* at Myrtle Gully and Old Farm Trail

Date	*Cortinarius*		*Russula*	
	Myrtle Gully	Old Farm Trail	Myrtle Gully	Old Farm Trail
09 Mar 99	10	2	2	2
13 Apr 99	3	3	5	0
15 Jun 99	3	4	0	2
06 Sep 99	0	1	0	1
10 Feb 00	0	0	0	0
21 Mar 00	0	0	0	0
18 May 00	6	2	3	0
22 Jun 00	5	11	0	1
09 Nov 00	5	2	0	1
12 Dec 00	2	1	2	2
09 Jan 01	0	0	0	0
06 Mar 01	0	0	0	0
03 May 01	10	8	1	0
28 Jun 01	1	2	2	0
31 Jul 01	0	1	1	1
15 Sep 01	1	0	0	0
27 Nov 01	1	0	0	1
17 Jan 02	0	1	3	4
21 Feb 02	2	0	2	2
07 May 02	0	0	0	0
Mean	2.45	1.90	1.05	0.85

number of species observed (Wilcoxon signed-rank test, $p = 0.287$), but when the number is converted into a proportion of the total number of species of all fungi (i.e., number of *Cortinarius*/total number of species), and the angular transformation is applied to the proportion, there is a significantly higher proportion of *Cortinarius* in Old Farm Trail than in Myrtle Gully (Wilcoxon signed-rank test, $p = 0.007$). For *Russula*, the total number of species clearly does not differ ($p = 0.826$), and after conversion into a proportion and use of the angular transformation, there is only marginal evidence of a higher proportion of *Russula* in Old Farm Trail than in Myrtle Gully ($p = 0.058$). *Cortinarius* is a genus that is indisputably mycorrhizal, and since Myrtle Gully is almost devoid of eucalypts, whereas they are dominant in Old Farm Trail, this might suggest that *Cortinarius* is more likely to be found in eucalypt woodlands than in very wet forests or gullies, an explanation that agrees with observations made at other sites in Tasmania.

Table 3 lists the total number of fungi species, from all orders and families, found in Myrtle Gully and in some other gully or wet sclerophyll environments of Mount Wellington (excluding Old Farm Trail) visited no more than 16 days apart. The tests produced only marginal evidence, at most, of higher numbers in Myrtle Gully than in the other site: two-sample t-test $p = 0.056$; Wilcoxon–Mann–Whitney test $p = 0.079$; Median test $p = 0.041$. This suggests that there is not a great difference between various gullies and wet sclerophyll sites that are in close proximity to each other. One factor leading to greater species richness in Myrtle Gully than elsewhere is that the gully is longer and spans a greater altitude range (300–580 m) than any of the other sites.

DISCUSSION

The 130 species listed in the Appendix is a preliminary attempt at cataloguing the mycobiota (Agaricales) of Mount Wellington, given that only a portion of the agarics have been named. Nevertheless, it should be seen as a beginning, and hopefully, more species will be added as further mycological studies are completed and published. For example, the authors are aware that a study of the genus *Mycena* in southeastern Australia is soon to be published (C. A. Grgurinovic, pers. comm.), which will increase the number of named species in a genus that is both widespread and abundant in Tasmania, forming a conspicuous component of the mycobiota on wood and litter.

Another work that provides names for five taxa that occur on Mount Wellington is the unpublished thesis of Y. S. Chang (1992). Although these names are not validly published, the author plans to submit them for formal publication (Y. S. Chang, pers. comm.). The five taxa are (1) *Pholiota* sp. ('*pallidocaulis*'), a not uncommon species, usually on wood, characterised by a pale coloured upper stipe with conspicuous yellow rhizomorphs at the base, and a pileus that is viscid and scaly, at first light yellow, then brownish orange, becoming light brown throughout. The pleurocystidia do not become yellow in alkaline solution; (2) *Pholiota* sp. ('*viscofumosa*'), an uncommon species characterised by a slimy, viscid, smoky grey, striate pileus with concentric whitish scales at the centre, and a whitish, flaky stipe becoming smooth and sordid brown later; (3) *Psilocybe* sp. ('*brunneo-albescens*'), a small, often umbonate, species growing on wood, brown at first but becoming whitish with drying, the drying taking place from the centre of the pileus outwards towards the margin;

TABLE 3
Comparison of Myrtle Gully with other wet gullies of Mount Wellington

Date visited Myrtle Gully	No. of species (Myrtle Gully)	Name of other wet sclerophyl site	Date visited other gully	No. of species (other)
09 Mar 99	72	Circle Track	11 Mar 99	48
13 Apr 99	73	Myrtle Forest Ck.	15 Apr 99	53
13 May 99	18	Strickland Falls/Lower Sawmill	13 May 99	32
15 Jun 99	59	Betts Vale	24 Jun 99	42
12 Aug 99	52	Lenah Valley/Lower Sawmill	12 Aug 99	24
06 Sep 99	37	Jacksons Bend	29 Aug 99	30
11 Nov 99	45	Betts Vale	26 Oct 99	19
30 Dec 99	13	Circle Track	08 Jan 00	23
10 Feb 00	4	Myrtle Forest	17 Feb 00	33
21 Mar 00	28	FernGlade	19 Mar 00	4
22 Jun 00	46	Jacksons Bend	24 Jun 00	31
09 Nov 00	60	O'Gradys & Betts Vale	07 Nov 00	31
12 Dec 00	27	Silver Falls S.T.	16 Dec 00	22
09 Jan 01	17	Jacksons Bend	16 Jan 01	8
06 Mar 01	7	N.W Bay River	10 Mar 01	18
03 May 01	102	Silver Falls S.T.	05 May 01	81
28 Jun 01	45	Fern Glade	05 Jul 01	49
31 Jul 01	63	Silver Falls S.T.	02 Aug 01	29
15 Sep 01	59	Myrtle Forest	25 Sep 01	21
27 Nov 01	54	N.W. Bay River	17 Nov 01	44
17 Jan 02	67	N.W. Bay River	01 Jan 02	49
21 Feb 02	59	Jacksons Bend	19 Feb 02	35
07 May 02	29	Silver Falls S.T.	11 May 02	32

(4) *Stropharia* sp. (*'formosa'*), a handsome, large species characterised by a chestnut brown pileus, grey lamellae, and an appendiculate margin, illustrated in Fuhrer & Robinson (1992, p.59) as *Stropharia* sp.; and (5) *Hypholoma fasciculare* (Huds.:Fr.) P.Kumm. var. (*'armeniacum'*), which has orange lamellae instead of greenish yellow lamellae when young, illustrated in Fuhrer & Robinson (1992, p.37) as *Hypholoma fasciculare.*

In addition, one of the present authors (GMG) is working on the taxonomy of the family Entolomataceae in Tasmania, and manuscripts are in preparation in which new species will be published. On Mount Wellington, she has identified 51 distinct species in the genus *Entoloma* and four species of *Rhodocybe*, most of which are new to mycology.

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APPENDIX
Species Descriptions of Mount Wellington Agaricales

Agaricus arvensis Schaeff. – This introduced species, like the 'field mushroom' *Agaricus campestris,* is encountered on grassy lawns and other disturbed environments. Illustrations: Shepherd & Totterdell (1988, p. 33); Young (2000, plate 1).

Agaricus austrovinaceus Grgur. & T.W.May – Characterised by a vinaceous brown, fibrillose pileus. Illustrations: Cole *et al.* (1984, plate 1), as *Agaricus vinacea*; Grgurinovic (1997, fig. 341), microscopic characters only.

Agaricus campestris L.:Fr. – This introduced species, like the 'horse mushroom' *Agaricus arvensis,* is encountered on grassy lawns, such as at the Waterworks Reserve and other disturbed environments. Illustrations: Macdonald & Westerman (1979, p. 21); Shepherd & Totterdell (1988, p. 33); Young (2000, plate 1).

Agaricus xanthodermus Genev. – Recognised by an immediate yellow-staining reaction when the base of the stipe is broken. Usually found on lawns in parks, gardens and disturbed areas. Illustrations: Shepherd & Totterdell (1988, p. 34); Fuhrer (2001, p. 15).

Agrocybe parasitica G.Stev. – Usually growing in clumps on wood of dead trees, characterised by a large, flaring annulus. Illustrations: Macdonald & Westerman (1979, p. 23), as *Agrocybe cylindracea*; Fuhrer & Robinson (1992, p. 22); Fuhrer (2001, p. 16).

Agrocybe pediades (Fr.:Fr.) Fayod – This species group is, like *Agrocybe praecox*, probably an introduction from the Northern Hemisphere. The small, smooth pileus, 1–3 cm diam., is hemispherical at first but becomes convex and cracked with age, usually has some shade of brown, and generally lacks an annulus. Usually found in grasslands, on dung or manure, or disturbed land. Illustration: Arora (1986, p. 468).

Agrocybe praecox (Pers.:Fr.) Fayod – The fairly large pileus (3–9 cm diam.) is off-white, pale tan or pale buff, dry or slightly tacky, smooth becoming cracked or fissured in age, is often found growing among woodchips or on dead wood. The thin, membranaceous veil may be fleeting. The species is very variable in all its parts. Illustration: Arora (1986, plate 102).

Amanita effusa (Kalchbr.) D.A.Reid – An easily recognised white species characterised by large pyramidal warts on the pileus. Illustration: Wood (1997, fig. 30).

Amanita muscaria (L.:Fr.) Lam. – The red to orange-red pileus (rarely yellow) covered with white warts make this introduced species one of the most recognisable and most frequently collected and photographed of all agarics. Illustrations: Macdonald & Westerman (1979, p. 25); Shepherd & Totterdell (1988, p. 36); Fuhrer & Robinson (1992, p. 22); Grgurinovic (1997, plate 33b); Young (2000, plate 1).

Amanita ochrophylla (Cooke & Massee) Cleland – Recognised by the dull yellow lamellae, bulbous base and persistent annulus. Illustrations: Grgurinovic (1997, plate 22); Fuhrer (2001, p. 18).

Amanita punctata (Cleland & Cheel) D.A.Reid – Recognised by the grey pileus with striate margin and the large sac-like volva at the base of the stipe. Illustrations: Young (2000, plate 2); Fuhrer (2001, p. 19).

Amanita umbrinella E.J.Gilbert & Cleland – Characterised by a brownish grey pileus, a smoky grey stipe bearing a prominent, strongly striated annulus, and a friable, fugacious volva. Illustrations: Bougher & Syme (1998, pp. 170–1); Fuhrer (2001, p. 20).

Amanita xanthocephala (Berk.) D.A.Reid & R.N.Hilton – A small species with an evanescent annulus but usually with a prominent volva and a scarlet, orange-red or orange-yellow pileus with striate margin and prominent warts. Illustrations: Shepherd & Totterdell (1988, p. 37); Grgurinovic (1997, plate 33a); Bougher & Syme (1998, pp. 172–3); Fuhrer (2001, p. 21).

Anthracophyllum archeri (Berk.) Pegler – This fan-shaped fungus with a much-reduced stipe is brick red or brownish red, and often profusely covers dead branches and twigs. Illustrations: Fuhrer & Robinson (1992, p. 24); Bougher & Syme (1998, pp. 190–1).

Armillaria hinnulea Kile & Watling – Confined to wet gullies and differing from *Armillaria novaezelandiae* by having a non-glutinous pileus and pink lamellae when mature.

Armillaria luteobubalina Watling & Kile – Occurs occasionally on the lower slopes of Mount Wellington, bordering the wet forests. Illustrations: Grgurinovic (1997, plate 2c); Bougher & Syme (1998, pp. 192–3); Fuhrer (2001, pp. 22–3).

Armillaria novaezelandiae (G.Stev.) Herink – Confined to wet gullies where it is abundant and parasitic on wet forest species. Differentiated from *Armillaria hinnulea* in having a viscid to glutinous pileus with a dark, scaly to punctate centre and whitish lamellae. Illustrations: Macdonald & Westerman (1979, p. 29), as *Armillaria mellea*; Shepherd & Totterdell (1988, p. 39), as *Armillaria* aff. *mellea*; Fuhrer & Robinson (1992, p. 24).

Asterophora mirabilis (May & Fuhrer) Redhead & Seifert – Species of this genus grow exclusively as a parasite of other agarics, usually on decaying *Russula* and *Lactarius.* Illustrations: May & Fuhrer (1995, p. 387), as *Nyctalis mirabilis.*

Bolbitius vitellinus (Pers.:Fr.) Fr. – Found in grassy and/or disturbed areas, and recognised by the viscid to glutinous yellow pileus and fragile whitish to pale yellowish stipe. Illustrations: Bougher & Syme (1998, pp. 230–1); Young (2000, plate 2), as *Bolbitius variicolor.*

Clitocybe clitocyboides (Cooke & Massee) Pegler – A funnel-shaped species with inflated hyphal elements (vesicles) in the pileus and may be conspecific with *Clitocybe phaeophthalma* (Pers.) Kuyper [= *Clitocybe hydrogramma* (Bull. & Vent.:Fr.) P.Kumm.] of the Northern Hemisphere. Illustrations: Phillips (1981, p. 51), as *C. hydrogramma*; Courtecuisse & Duhem (1995, fig. 299), as *C. phaeophthalma.*

APPENDIX cont.

Clitocybe semiocculta Cleland – An all-white species growing on wood, usually with dense tufts of white hairs at the base of the stipe. Uncommon. Illustration: Fuhrer & Robinson (1992, p. 30).

Collybia butyracea (Bull.:Fr.) P.Kumm. – Typically, this soil-borne species has a greasy or soapy feel to the pileus, and a stipe expanded at the base, but it is extremely variable. Illustration: Macdonald & Westerman (1977, pp. 33). Also known as *Rhodocollybia butyracea* (Bull.:Fr.) Lennox.

Collybia eucalyptorum Cleland – This species has free, close lamellae and a weak, hollow stipe. Unlike *Collybia butyracea*, it is found growing directly on wood.

Conchomyces bursiformis (Berk.) E.Horak – The rubbery texture, due to gelatinisation, is a key feature of this white-fleshed, uncommon species, found as eccentrically attached brackets on wood. Illustration: Fuhrer & Robinson (1992, p. 30).

Coprinus atramentarius (Bull.:Fr.) Fr. – Pileus cylindrical to narrowly oval at first, later becoming upturned. The lamellae are extremely close and thin, later autodigesting. Illustrations: Macdonald & Westerman (1979, p. 35); Shepherd & Totterdell (1988, p. 46); Fuhrer (2001, p. 24). Redhead *et al.* (2001) have transferred this species to *Coprinopsis*.

Coprinus comatus (O.F.Müll.) Fr. – Pileus cylindrical, surface densely covered with shaggy white to brown scales, autodigesting from below. Illustrations: Macdonald & Westerman (1979, p. 37); Shepherd & Totterdell (1988, p. 47); Grgurinovic (1997, plate 34a); Bougher & Syme (1998, pp. 290–1); Young (2000, plate 5).

Coprinus disseminatus (Pers.:Fr.) Gray – A smallish species usually recognised by the habit of growing in troops on or near wood. Young fruiting bodies are creamy yellow, becoming grey prior to blackening as a result of autodigestion. Illustration: Shepherd & Totterdell (1988, p. 49); Grgurinovic (1997, plates 3a, 3b and 34b); Young (2000, plate 12); Fuhrer (2001, p. 25). Redhead *et al.* (2001) have transferred this species to *Coprinellus*.

Cortinarius abnormis Watling & T.W.May – This all-brown species usually has copious brown velar remains covering the stipe. Illustration: Fuhrer (2001, p. 37).

Cortinarius archeri Berk. – One of the most striking of all members of the genus, this species is readily recognised by the violet, glutinous fruiting bodies. Illustrations: Shepherd & Totterdell (1988, p. 50); Grgurinovic (1997, plate 15d); Bougher & Syme (1998, pp. 242–3); Young (2000, plate 6); Fuhrer (2001, p. 30).

Cortinarius australiensis (Cleland & Cheel) E.Horak – The very large, white fruiting bodies of this species have a membranaceous annulus, reminiscent of *Rozites* spp., on their stipe. Illustrations: Shepherd & Totterdell (1988, p. 96), as *Rozites austaliensis*; Grgurinovic (1997, plate 1a); Bougher & Syme (1998, pp. 244–5); Fuhrer (2001, p. 32).

Cortinarius austroalbidus Cleland & J.R.Harris – A white *Cortinarius* with pale buff hues at maturity and an odour of curry. Illustration: Fuhrer (2001, p. 29).

Cortinarius austroviolaceus B.Gasparini – A striking, concolorous, very dark violet species. Illustration: Gasparini (2001a).

Cortinarius phalarus N.L.Bougher & R.N.Hilton – Characterised by a medium-sized fruiting body with a tawny-brown pileus with white remains from the universal veil and a very distinctive white volva at the base of the stipe. This is one of several closely related volvate species occurring in eastern Australia. Illustration: Bougher & Syme (1998, pp. 254–5).

Cortinarius rotundisporus Cleland & Cheel – The deep metallic blue of the pileus, with a yellow-ochre disc, characterises this species. Illustrations: Grgurinovic (1997, plate 10c); Bougher & Syme (1998, pp. 256–7); Fuhrer (2001, p. 36).

Cortinarius sinapicolor Cleland – The extremely glutinous, mustard-coloured pileus and stipe distinguish this species. Illustrations: Bougher & Syme (1998, pp. 258–9); Fuhrer (2001, p. 34).

Cortinarius vinosipes B.Gasparini – The distinctive feature of this species is the rose colour that is present throughout the entire fruiting body in the early stage of development. Illustration: Gasparini (2001b).

Crepidotus applanatus (Pers.) P.Kumm. – This brown-spored species, which may attain a diameter of 10 cm or more, is characterised by a soft, watery texture. Illustrations: Macdonald & Westerman (1979, p. 43); Fuhrer & Robinson (1992, p. 30); Fuhrer (2001, p. 40).

Crepidotus variabilis (Pers.:Fr.) P.Kumm. – A small white species that comes in a range of sizes, usually very variable within a single collection; lamellae white at first, prior to maturation of the brown spores. Illustrations: Macdonald & Westerman (1979, p. 45); Fuhrer & Robinson (1992, p. 31); Fuhrer (2001, p. 41).

Cyptotrama aspratum (Berk.) Redhead & Ginn – This wood-inhabiting species is recognised by the orange pileus covered at first with shaggy warts, and the orange colour near the base of the stipe. Illustration: Young (2000, plate 25).

Cystoderma amianthinum (Scop.:Fr.) Konrad & Maubl. – Readily recognised by the mealy granules that cover the stipe below the annulus and the young pileus. Illustration: Fuhrer & Robinson (1992, p. 31).

Dermocybe austroveneta (Cleland) M.M.Moser & E.Horak – Recognised by the green cap and yellow stipe, but the colours are extremely variable. Illustrations: Young (2000, plate 6), as *Cortinarius austrovenetus*; Fuhrer (2001, p. 31).

Dermocybe kula Grgur. – One of several red-coloured species of this genus in Tasmania, this fungus has a dark blood-red pileus and a red stipe. Illustration: Grgurinovic (1997, plate 12b). The illustration in Fuhrer (2001, p. 39), under the name *Cortinarius* aff. *sanguineus*, may be of this species.

Dermocybe splendida E.Horak – Characterised by the brilliant paprika-coloured orange-red lamellae. The stipe may be yellow or have varying amounts of red and yellow. Illustrations: Bougher & Syme (1998, pp. 264–5); Fuhrer (2001, p. 13).

APPENDIX cont.

Descolea phlebophora E.Horak – Differs from *Descolea recedens* in the less robust habit and in the spindly stipe with a whitish, rather than a brown, annulus.

Descolea recedens (Cooke & Massee) Singer – Recognised when young by the abundant light brown floccules that cover the wrinkled pileus and by the striate brown annulus. The lamellae may be straight or crumpled. The species *Descolea maculata* N.L.Bougher in Bougher & Syme (1998, pp. 266–7), is very similar. Illustrations: Fuhrer & Robinson (1992, p. 30), as *Descolea* sp.; Grgurinovic (1997, plate 7b); Young (2000, plate 20), as *Pholiota recedens.*

Entoloma aromaticum E.Horak – Pileus to 2 cm, conical, buff-pink, hygrophanous, developing a gold sheen, lamellae adnexed to free, pale pink-buff, stipe slender, buff-pink with aeriferous white basal tomentum, odour strong bubblegum or aromatic, taste similar.

Entoloma gelatinosum E.Horak – A robust species, tricholomatoid in stature, pileus to 5 cm, grey-brown with pink hues at margin, which disappear rapidly with age, lamellae adnexed, whitish at first, turning pink, stipe stout, grey-brown, tapering downwards. All tissues gelatinised; hence the fruiting body is very lubricous.

Entoloma panniculum (Berk.) Sacc. – Pileus to 3 cm, plano–convex, stunning deep blue-violet, estriate, squamulose, lamellae adnexed, pink, stipe very slender, squamulose, deep blue-violet with aeriferous white basal tomentum.

Entoloma procerum G.Stev. – Pileus to 3 cm, often conical with small sharp umbo, dark chocolate brown, lamellae whitish with brownish hues, margin dark brown, stipe slender, pale off-white or bone with brownish hues and aeriferous white basal tomentum, spores large, twinned tetrahedral.

Entoloma rodwayi (Massee) E.Horak – Pileus to 3 cm, green, translucent striate, becoming brownish with age, drying a blue-green, lamellae flesh pink, stipe pale green with aeriferous white basal tomentum. Illustration: Fuhrer & Robinson (1992, p. 33).

Entoloma sericellum (Fr.:Fr.) P.Kumm. – Pileus to 3 cm, convex, pure white developing pinkish or ochraceous hues with age, lamellae adnate, pallid pink deepening with age, stipe slender, pure white. Illustration: Fuhrer & Robinson (1992, p. 32), as *Entoloma* sp. *c.*

Entoloma viridomarginatum (Cleland) E.Horak – Pileus to 2 cm, dark green, squamulose at the centre, becoming quite orange with age, lamellae pink-orange with hints of green, margin usually dark green or sometimes dark blue, stipe dark green with aeriferous white basal tomentum, slender, stipititrama orange. Illustration: Grgurinovic (1997, fig. 252), microscopic characters only.

Flammulina velutipes (Curtis:Fr.) Singer – Characterised by a caespitose habit on wood and viscid, ochraceous to brown pileus with velvety brown stipe. Illustrations: Shepherd & Totterdell (1988, p. 24 and p. 57), as *Flammulina veluticeps*; Fuhrer & Robinson (1992, p. 35).

Galerina hypnorum (Schrank:Fr.) Kühner – A small species growing amongst moss. Illustrations: Macdonald & Westerman (1979, p. 47); Fuhrer (2001, p. 43).

Galerina patagonica Singer – The brown pileus usually has an umbonate centre, with the stipe bearing the remains of the partial veil. One of the few species of the genus that is found on wood. Illustration: Grgurinovic (1997, plate 7d); Young (2000, plate 15).

Gymnopilus junonius (Fr.:Fr.) P.D.Orton – A large to very large brown to golden brown species often growing in clusters at the base of eucalypts. Illustrations: Macdonald & Westerman (1979, p. 49); Shepherd & Totterdell (1988, p. 59); Fuhrer (2001, p. 45), all as *Gymnopilus pampeanus*, which was recently reduced to synonymy with *G. junonius* (see Rees & Strid, 2001).

Hygrocybe astatogala (R.Heim) Heinem. – A conical species extremely variable in colour that may become wholly black from blackish fibrils at maturity, or blacken upon bruising. Illustrations: Fuhrer & Robinson (1992, p. 38), as *Bertrandia astatogala*; Grgurinovic (1997, plate 20b).

Hygrocybe aurantiopallens (E.Horak) A.M.Young – A small, dry, apricot-orange species with occasional intervenose lamellae. Illustration: Fuhrer & Robinson (1992, p. 38), as *Camarophyllus aurantiopallens.* The photograph on the same page identified as *Camarophyllus apricosa* is probably the same species, the deep apricot-orange being typical of Tasmanian material.

Hygrocybe cheelii A.M.Young – Pileus dry, bright pinkish mauve or lilac, lamellae mauve-lilac and deeply decurrent, distant and thick, stipe concolorous but yellow at the base. Illustration: Willis (1963, plate 9, fig.1) as *Cantharellus lilacinus.*

Hygrocybe chromolimonea (G.Stev.) T.W.May & A.E.Wood – Recognised by the yellow colour with all parts glutinous. Illustration: Fuhrer & Robinson (1992, p. 41), as *Gliophorus chromolimoneus.*

Hygrocybe erythrocrenata Monks & A.K.Mills – Pileus hemispherical, campanulate or conical, brownish red or reddish brown, hygrophanous, becoming pale yellow, then greyish orange on drying, margin pellucid, crenate to subcrenate, lamellae subdecurrent to decurrent, distant, white, whitish, pallid pinkish grey or lilac, stipe red. Illustration: Mills & Monks (1993, fig. 1c–f).

Hygrocybe firma (Berk. & Broome) Singer – There are several species of *Hygrocybe* in Tasmania with a red pileus and a red stipe, which are difficult to distinguish. *Hygrocybe firma* has a brilliant red-scarlet pileus when fresh, similarly coloured stipe and lamellae, and dimorphic spores. Illustration: Young (2000, front cover). The species illustrated in Fuhrer & Robinson (1992, p. 44), as *Hygrocybe procera*, may be the same.

Hygrocybe graminicolor (E.Horak) T.W.May & A.E.Wood – Pileus and stipe viscid or glutinous, grass-green, lamellae adnate to decurrent, white to pale green, with a fine glutinous thread along the margin. Dries pink. Illustrations: Fuhrer & Robinson (1992, p. 40), as *Gliophorus graminicolor.*

APPENDIX cont.

Hygrocybe lewellinae (Kalchbr.) A.M.Young – Lilac in all the parts with the pileus split at various places along the margin such that the two faces of a lamella are pulled apart. Illustration: Fuhrer & Robinson (1992, p. 43), as *Humidicutis rosella*; Young (2000, plate 8); Fuhrer (2001, p. 48), as *Hygrophorus lewellinae.*

Hygrocybe lilaceolamellata (G.Stev.) E.Horak – Pileus dry or slightly viscid, brown, lamellae lilac, adnate to decurrent. Illustration: Fuhrer & Robinson (1992, p. 42).

Hygrocybe mavis (G.Stev.) E.Horak – Concolorous white in all the parts with the pileus split in places along the margin such that the two faces of a lamella are pulled apart. Illustration: Fuhrer & Robinson (1992, p. 43), as *Humidicutis pura.*

Hygrocybe miniata (Fr.:Fr.) P.Kumm. – This species differs from *Hygrocybe firma* in having orange-red to yellowish lamellae. Illustrations: Fuhrer & Robinson (1992, p. 42); Bougher & Syme (1998, pp. 178–9). The species illustrated in Fuhrer & Robinson (1992, p. 42) as *Hygrocybe* aff. *coccinea* is part of this complex of species.

Hygrocybe pseudograminicolor A.M.Young – Similar to *Hygrocybe graminicolor* in the colour of the pileus and stipe and in having a glutinous margin to the lamellae, but the lamellae are yellow-green and the fruiting body remains green rather than becoming pink upon drying. Illustration: Young & Wood (1997, p. 994).

Hygrocybe reesiae A.M.Young – Pileus, lamellae and stipe pale to intense lilac, lacking pink or yellow tints. Illustration: Young & Wood (1997, p. 924).

Hygrocybe rodwayi (Massee) A.M.Young – Concolorous cream throughout, pileus dry, convex or becoming plane, occasionally funnel-shaped, margin entire, lamellae decurrent, stipe tapered downwards. Illustration: Fuhrer & Robinson (1992, p. 39), as *Camarophyllus rodwayi.*

Hygrocybe stevensoniae T.W.May & A.E.Wood – Recognisable by the viscid or glutinous green pileus and stipe, and white lamellae that lack a glutinous thread on the margin. Dries pink. Illustrations: Fuhrer & Robinson (1992, p. 41), as *Gliophorus viridis*; Young (2000, plate 8).

Hygrocybe taekeri A.M.Young – Tasmanian material illustrated in Fuhrer & Robinson (1992, p. 45), as *Hygrocybe* sp., having a green pileus and stipe with bright orange lamellae with some cross-venation, may be the same as this species described from New South Wales. Illustration: Young & Wood (1997, p. 1003).

Hygrophoropsis aurantiaca (Wulfen:Fr.) Maire – The felt-like or velvety funnel-shaped pileus is variable in colour from whitish to brown, the lamellae are decurrent, close, some shade of orange or yellow, and may have some dichotomous forking. Illustration: Arora (1986, plate 110). The photograph in Shepherd & Totterdell (1988, p. 64), attributed to this species, is actually of *Paxillus muelleri.*

Hygrophorus involutus G.Stev. – Recognised by the pale apricot-yellow viscid pileus, similarly coloured closely spaced lamellae, and a long tapering stipe. There is also an all-white form of the species. Illustrations: Fuhrer & Robinson (1992, p. 45); the white form of the species is illustrated on p. 39, but misnamed as *Camarophyllus niveus.*

Hypholoma aurantiaca (Cooke) Faus – Pileus reddish brown or red, and almost always found on woodchips in cultivated areas. Also known as *Stropharia aurantiaca* (Cooke) P.D.Orton. Illustration: Grgurinovic (1997, plate 28a).

Hypholoma australe O.K.Mill. – Pileus brick to fulvous at the disc, yellowish brown outside the disc, lubricous, lamellae adnate, greenish at first, fairly close, stipe yellowy off-white, imbued with brick hues, squamulose in places with scurfy whitish scales. This species may just be a form of *Hypholoma sublateritium.* Illustrations: Bougher & Syme (1998, pp. 232–3); Fuhrer (2001, p. 49).

Hypholoma brunneum (Massee) D.A.Reid – Pileus dark brown with whitish veil remnants around the margin. Usually on wood. Illustration: Fuhrer & Robinson (1992, p. 36).

Hypholoma fasciculare (Huds.:Fr.) P.Kumm. – Pileus often sulphur yellow with a red-brown or orange-brown centre, stipe concolorous with pileus, lamellae greenish yellow when young. On wood, buried wood or in wood-rich soil, usually caespitose. Illustrations: Macdonald & Westerman (1979, p. 67); Shepherd & Totterdell (1988, p. 65); Grgurinovic (1997, plate 4a); Young (2000, plate 17).

Hypholoma sublateritium (Fr.) Quél. – Pileus brick red to orange-brown, stipe white or cream and densely covered with floccules when young, lamellae yellow-green when young. At the base of trees or on buried wood. Illustrations: Macdonald & Westerman (1979, p. 69); Shepherd & Totterdell (1988, p. 66); Fuhrer & Robinson (1992, p. 36); Young (2000, plate 30).

Inocybe cystidiocatenata Grgur. – Pileus and stipe minutely whitish-hairy. Illustration: Grgurinovic (1997, plate 29c).

Lacrymaria asperospora (Cleland) Watling – Recognised by the fibrillose pileus with appendiculate margin, fringed lamellae and, microscopically, by the distinctive, warted spores. Also known as *Psathyrella asperospora* (Cleland) Guzmán, Bandala & Montoya. Illustrations: Shepherd & Totterdell (1988, p. 92), as *Psathyrella asperospora*; Bougher & Syme (1998, pp. 296–7), as *Psathyrella asperospora*; Young (2000, plate 18); Fuhrer (2001, p. 50).

Lactarius clarkeae Cleland – Pileus and stipe with distinctive apricot-orange colour, and white to cream lamellae that exude latex. Illustrations: Bougher & Syme (1998, pp. 132–3); Young (2000, plate 18).

Lactarius eucalypti O.K.Mill. & R.N.Hilton – A smallish, common species recognised by the pinkish to rusty brown colour and readily exuded white latex. Illustrations: Fuhrer & Robinson (1992, p. 47), as *Lactarius* aff. *subdulcis*; Bougher & Syme (1998, pp. 134–5).

Lepiota haemorrhagica Cleland – The lamellae are cream-coloured, but characteristically turn blood red when bruised.

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Lepista nuda (Bull.:Fr.) Cooke – Recognised by the purple-violet colours of the pileus, lamellae and stipe, this fungus can attain a large size. Found in native forests as well as disturbed habitats. Illustration: Fuhrer (2001, p. 52).

Macrocystidia cucumis (Pers.:Fr.) Josserand – Pileus to 2 cm, conical or convex, red-brown, lubricous, glabrous, margin faintly striate, hygrophanous, lamellae adnexed, ventricose, to 3 mm deep, pink-cream, stipe very slender, wiry, blackish brown, lighter at apex, strong odour of cod liver or linseed oil, taste of cucumber, cheilocystidia huge. Not previously reported from Australia, Tasmanian material closely fits the description of this Northern Hemisphere species. Illustration: Courtecuisse & Duhem (1995, fig. 979).

Macrolepiota konradii (Huijsman ex P.D.Orton) M.M.Moser – This species, and other closely related species such as *Macrolepiota gracilenta* (Krombh.) Wasser, has a confused taxonomy. It is found in disturbed areas or in parks and gardens (e.g., the Waterworks Reserve), but occasionally appears in the bush, usually along roads where there has been disturbance. Illustrations: Macdonald & Westerman (1979, p. 53), as *Lepiota gracilenta*; Shepherd & Totterdell (1988, p. 75); Bougher & Syme (1998, pp. 186–7); Young (2000, plate 18).

Marasmiellus affixus (Berk.) Singer – This small, fan-shaped fungus, often profusely covering small twigs and bark, is recognised by the strong, unpleasant odour. Illustration: Fuhrer & Robinson (1992, p. 49).

Marasmius elegans (Cleland) Grgur. – Characterised by the velvety red-brown pileus and the two-toned stipe, whitish above and red-brown below. Illustrations: Macdonald & Westerman (1979, p. 57); Shepherd & Totterdell (1988, p. 43), as *Collybia elegans*; Bougher & Syme (1998, pp. 202–3); Fuhrer (2001, p. 54).

Melanophyllum haematospermum (Bull.:Fr.) Kreisel – This uncommon species with a greenish or greyish brown spore print is usually placed in the Agaricaceae. The pileus and stipe are granular-mealy and the remains of a veil often hang from the pileus margin. Illustration: Fuhrer & Robinson (1992, p. 49), as *Melanophyllum echinatum*.

Melanotus hepatochrous (Berk.) Singer – A small brown pileus and a reduced but distinct stipe characterise this rarely reported, but not uncommon, species growing on rotting wood. Illustration: Shepherd & Totterdell (1988, p. 54), misidentified as *Crepidotus eucalyptorum*.

Mycena albidocapillaris Grgur. & T.W.May – Concolorous white to whitish, pileus very small with striate margin. Illustrations: Shepherd & Totterdell (1988, p. 82 and Fuhrer & Robinson (1992, p. 52), both as *Mycena subcapillaris*. Tasmanian material is in need of further study, as there appears to be more than one species of small, white-coloured *Mycena* in Tasmania.

Mycena austrofilopes Grgur. & A.A.Holland – Pileus conical, pale grey or smoky brown, umbo brownish, hygrophanous, lamellae adnexed, pale grey, pellucid, stipe very long and slender, pale grey, basidia two-spored.

Mycena austrororida Singer – This is a small species on wood whose stipe is thickly covered with clear gluten and whose whitish pileus may be covered with fine brown dots. Illustration: Fuhrer (2001, p. 57).

Mycena clarkeana Grgur. – This species was segregated from *Mycena vinacea* Cleland by Grgurinovic (1997). It occurs in clusters on or near wood, rather than soil, and has notched to adnexed lamellae lacking a contrasting margin. Illustrations: Macdonald & Westerman (1979, p. 63), as *Mycena vinacea*; Shepherd & Totterdell (1988, p. 82), as *Mycena vinacea*; Grgurinovic (1997, plate 17a); Young (2000, plate 19), as *Mycena vinacea*.

Mycena cystidiosa (G.Stev.) E.Horak – This tall, dark brown species having a long, slender brown stipe with strigose hairs at the base grows on forest litter and is easily recognisable by the abundance of slender, white, rhizomorph-like structures that accompany its appearance. Illustrations: Shepherd & Totterdell (1988, p. 83), as *Mycena* aff. *eucalyptorum*; Fuhrer & Robinson (1992, p. 53), as *Mycena hispida*; Grgurinovic (1997, plate 17e).

Mycena epipterygia (Scop.:Fr.) Gray – In Tasmanian material, the pileus is yellowish, fawn or grey, with the stipe usually yellow or lime-green, glutinous-viscid, often with cucumber odour when broken. This group has been studied intensively by Grgurinovic (ined.), with one new species, *Mycena nyula* Grgur. already published (Grgurinovic, 1997) and several others to appear. She considers all Australian material to be different from the true *Mycena epipterygia*. Illustrations: Shepherd & Totterdell (1988, p. 80); Fuhrer & Robinson (1992, p. 50); Young (2000, plate 19); Fuhrer (2001, p. 58 and front cover).

Mycena interrupta (Berk.) Sacc. – The pileus is uniquely sky-blue with a darker centre. On wood. Illustrations: Macdonald & Westerman (1979, p. 59); Fuhrer & Robinson (1992, p. 53); Fuhrer (2001, p. 59).

Mycena kurramulla Grgur. – This species is differentiated from other pink-vinaceous species by the combination of subdecurrent, whitish, marginate lamellae and habit on wood. Illustration: Grgurinovic (1997, plate 16d).

Mycena leaiana (Berk.) Sacc. var. *australis* Dennis – An uncommon but readily recognised species with bright orange lamella edges. Found on wood. Illustration: Fuhrer & Robinson (1992, p. 53).

Mycena pura (Pers.:Fr.) P.Kumm. – Pileus and stipe vinaceous purple or purple-brown, pileus margin striate, lamellae concolorous or whitish, lacking a contrasting margin. This species is extremely variable, but it consistently has a radish-like taste and odour and is found on soil. Illustrations: Bougher & Syme (1998, pp. 204–5); Fuhrer (2001, p. 60).

Mycena sanguinolenta (Alb. & Schwein. : Fr.) P.Kumm. – A brownish red species with marginate lamellae and a stipe that exudes reddish latex when crushed.

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Illustrations: Shepherd & Totterdell (1988, p. 58 and p. 82), the former misidentified as *Galerina marginata*; Grgurinovic (1997, plate 16b); Fuhrer (2001, p. 61).

Mycena subgalericulata Cleland – This often-illustrated species is found on wood, with a conical to convex brown pileus and striate margin, and is probably part of a group in need of further study. Illustrations: Macdonald & Westerman (1979, p. 61); Shepherd & Totterdell (1988, p. 81); Bougher & Syme (1998, pp. 206–7); Young (2000, plate 19).

Mycena viscidocruenta Cleland – Pileus vividly blood red, very viscid to glutinous when moist, and with subdecurrent, marginate lamellae. Illustrations: Macdonald & Westerman (1979, p. 65); Shepherd & Totterdell (1988, p. 81); Young (2000, plate 19).

Omphalina chromacea (Cleland) T.W.May & A.E.Wood – A small species characterised by a bright yellow colour and a funnel-shaped pileus. It is one of the few lichen-forming Basidiomycetes. Illustrations: Macdonald & Westerman (1979, p. 71); Bougher & Syme (1998, pp. 208–9); Fuhrer (2001, p. 62).

Omphalotus nidiformis (Berk.) O.K.Mill. – This large to very large bioluminescent species with decurrent lamellae may be fan-shaped, shell-shaped or have a depressed centre, with the variable fruiting bodies usually having some purplish grey, cream, and reddish brown blotches. Illustrations: Macdonald & Westerman (1979, pp. 75), as *Pleurotus nidiformis*; Shepherd & Totterdell (1988, pp. 90–1), as *Pleurotus nidiformis*; Grgurinovic (1997, plates 1b and 29d); Bougher & Syme (1998, pp. 210–1); Young (2000, plates 21 and 26); Fuhrer (2001, pp. 70–1).

Oudemansiella radicata (Relhan:Fr.) Singer – Pileus brownish, viscid to glutinous when young or moist, lamellae very white, and stipe with a long, tapering, rooting base below soil level. Illustrations: Macdonald & Westerman (1979, p. 73); Shepherd & Totterdell (1988, p. 85); Bougher & Syme (1998, pp. 220–1), as *Xerula australis*; Young (2000, plate 20); Fuhrer (2001, p. 67).

Panellus ligulatus E.Horak – Characterised by small, tongue-shaped or spoon-shaped orange fruiting bodies growing on wood. The lack of a blueing reaction of the spores to Melzer's reagent means that the species is uncomfortably placed in *Panellus*. Illustration: Bougher & Syme (1998, pp. 212–3).

Panellus longinquus (Berk.) Singer – Readily recognised by the shell-like habit on wood, pink gelatinised viscid pileus and the very reduced stipe. Illustration: Fuhrer & Robinson (1992, p. 54).

Panellus stipticus (Bull.:Fr.) P.Karst. – This small, wood-inhabiting brown fan has lamellae that may be intervenose and that exude a sticky latex. The stipe is short, broad and often greyish. Illustrations: Fuhrer & Robinson (1992, p. 54); Fuhrer (2001, p. 68).

Paxillus curtisii Berk. – A very soft, but moderately large, white or yellowish fan lacking a true stipe, found on dead wood. The yellow lamellae often have a crinkled appearance.

Paxillus muelleri Berk. – The funnel-shaped pileus and decurrent lamellae with occasional forking characterise this species. Recently renamed as *Austropaxillus muelleri* (Berk.) Bresinsky & M.Jarosch. Illustrations (several of which as *Paxillus infundibuliformis*): Shepherd & Totterdell (1988, p. 88 and p. 64), the latter misidentified as *Hygrophoropsis aurantiaca*; Fuhrer & Robinson (1992, p. 61); Bougher & Syme (1998, pp. 286–7); Young (2000, plate 20); Fuhrer (2001, p. 82).

Pholiota multicingulata E.Horak – Characterised by distinctive bands of brown scales circling the stipe. However, there are forms of this species that lack these bands or are sparsely or irregularly scaly. See *Pholiota squarrosipes* (below) for a discussion of microscopic differences. Illustration: Bougher & Syme (1998, pp. 234–5).

Pholiota squarrosipes Cleland – A medium brown to pale yellowish brown species that has brown scales irregularly placed around the stipe, not in regular bands as in *Pholiota multicingulata* (above), with which it can be confused. Microscopically the two species are readily separable, as *P. squarrosipes* has small, peg-like, embedded cystidia that become yellow in alkali, whereas *P. multicingulata* has larger, projecting, mostly hyaline cystidia. Illustration: Shepherd & Totterdell (1988, p. 89).

Phylloporus rhodoxanthus (Schwein.:Fr.) Bres. – This is probably a species complex (Watling & Gregory, 1991) and most Tasmanian collections may be referred to this complex. The luteous yellow lamellae, with frequent forking and cross-venation, contrasting with the dark brown, velvety pileus surface of robust habit, are characteristic. Illustrations: Macdonald & Westerman (1979, p. 89), as *Phylloporus hyperion*; Grgurinovic (1997, plate 16a).

Pleurotus purpureo-olivaceus (G.Stev.) Segedin – Pileus tongue-shaped or fan-shaped, olivaceous with areas of straw yellow or pale cream, margin inrolled, velvety-fibrillose, lamellae strongly decurrent, some shade of grey, stipe short but well-developed. On decaying, fallen wood, this is an uncommon species in Tasmania.

Pluteus atromarginatus (Konrad) Kühner – Recognised by the pink lamellae when mature, with prominent dark edges to the lamellae, and microscopically by three distinctly different types of cystidia. Illustrations: Bougher & Syme (1998, pp. 224–5); Young (2000, plate 21).

Pluteus cervinus (Schaeff.) P.Kumm. – Macroscopically very similar to *Pluteus atromarginatus* (above), but this species lacks the prominent dark edge to the lamellae when mature. Illustration: Grgurinovic (1997, plate 23a).

Psathyrella echinata (Cleland) Grgur. – A brown species found in large numbers on rotting wood. Young specimens may be covered all over with shaggy fibrils. Illustrations: Fuhrer & Robinson (1992, p. 57), as *Psilocybe echinata*; Grgurinovic (1997, plate 3d & e).

Psilocybe subaeruginosa Cleland – This variable species has an olive-brown to golden-brown pileus and a white stipe bruising blue. Illustrations: Shepherd &

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Totterdell (1988, p. 93), as *Psilocybe* sp.; Grgurinovic (1997, plate 4b); Young (2000, plate 22); Fuhrer (2001, p. 73).

Rickenella fibula (Bull. & Vent.:Fr.) Raithelh. – The small orange to pale orange fruiting bodies are conical to convex at first, becoming centrally depressed later with deeply decurrent lamellae. Usually found growing amongst moss. Illustrations: Grgurinovic (1997, plates 19d and 32c); Bougher & Syme (1998, pp. 214–5).

Rozites foetens Bougher – Recognised by the membranaceous veil, the shaggy tufts of hair covering the pileus and stipe and very unpleasant odour. Illustration: Fuhrer & Robinson (1992, p. 56), as *Rozites* sp.

Russula albonigra (Krombh.) Fr. – Flesh initially white, turning dark grey after bruising or cutting. Tasmanian specimens probably differ from the Northern Hemisphere form of the species, but may be the same as the species illustrated in Bougher & Syme (1998, pp. 142–3), which they call *Russula* aff. *albonigra*.

Russula clelandii O.K.Mill. & R.N.Hilton – Pileus red to purple, lamellae white or cream-coloured, stipe pink, pileipellis gelatinised. Illustration: Shepherd & Totterdell (1988, p. 97), as *Russula mariae*; Bougher & Syme (1998, pp. 144–5); Young (2000, plate 22), as *Russula mariae*; Fuhrer (2001, p. 75).

Russula lenkunya Grgur. – This recently renamed and redescribed species has violet colours in the pileus and pink or vinaceous colours in the stipe. The lamellae are described from South Australian material (Grgurinovic, 1997) as being white, whereas those of the Tasmanian material are cream to yellow. Microscopically, they agree in having a ciliate pileipellis of septate hairs subtended by cells, a feature not shared by other *Russula* species having red, purple or violet in the pileus. Illustration: Grgurinovic (1997, fig. 26), microscopic characters only.

Russula neerimea Grgur. – Pileus buff or yellowy tan with striate–sulcate margin, tacky to viscid when moist, lamellae creamy white, stipe white, odour and taste mild. The macroscopic and microscopic characters suggest that Tasmanian material is the same as this species recently renamed and redescribed from South Australia (Grgurinovic, 1997). Illustrations: Grgurinovic (1997, fig. 36), microscopic characters only; Bougher & Syme (1998, pp. 152–3).

Russula persanguinea Cleland – Recognised by the red, easily peeled pileus, white stipe and white crowded lamellae. Illustrations: Fuhrer & Robinson (1992, p. 58), as *Russula* sp. (b); Grgurinovic (1997, plate 5c); Bougher & Syme (1998, pp. 154–5); Fuhrer (2001, p. 75).

Simocybe phlebophora E.Horak – Pileus hemispherical in youth, brown, olivaceous or drab, disc coarsely wrinkled upon drying, margin striate, lamellae adnate, brown or greyish, margin fimbriate, stipe some shade of buff, slender, equal, pruinose in the upper half, spores pale brown, smooth, 7–8 x 4–5 µm, pileipellis with pear-shaped terminal cells. On wood or soil. Tasmanian material appears to be conspecific with the New Zealand species, as the wrinkled centre to the pileus is distinctive.

Tubaria rufofulva (Cleland) D.A.Reid & E.Horak – The fruiting body is characterised by its growth on wood and the deep maroon, claret or burgundy red colour throughout, and some traces of the remains of a veil on the stipe. Illustration: Bougher & Syme (1998, pp. 238–9).

Xeromphalina leonina (Massee) E.Horak – The tiny pale brown pileus of this fungus with decurrent lamellae is conspicuous only because the species tends to form huge colonies on decaying wood. Illustration: Fuhrer (2001, p. 66).

ALLOCASUARINA CRASSA L. JOHNSON (CASUARINACEAE): A REVISED DESCRIPTION, WITH NOTES ON DISTRIBUTION AND HABITAT

by Richard Schahinger

(with one table, one text-figure, six plates and an appendix)

SCHAHINGER, R., 2002 (31:xii): *Allocasuarina crassa* L. Johnson (Casuarinaceae): a revised description, with notes on distribution and habitat. *Papers and Proceedings of the Royal Society of Tasmania* 136: 101–106. ISSN 0080–4703. Threatened Species Unit, Department of Primary Industries, Water and Environment, GPO Box 44, Hobart, Tasmania 7001, Australia.

A revised description of the Tasmanian endemic *Allocasuarina crassa* L. Johnson is given, and its distribution, habitat and conservation status discussed. A new key to the *Allocasuarina* species in Tasmania is provided.
Key Words: *Allocasuarina crassa*, Cape Pillar, Tasman Peninsula, she-oaks, fire.

INTRODUCTION

The opportunity is taken here to provide a revised description of *Allocasuarina crassa* L. Johnson, and to give notes on its distribution and habitat. The impetus for the revision came in December 1997, when I came across a stand of 60–80 *Allocasuarina* trees of unusual form in the Tasman National Park in southeastern Tasmania. The largest of the trees resembled an old Dutch elm, with a stout trunk separating into several ascending branches (plates 1 and 2). The size and vestiture of the branchlet articles and the dimensions and character of the fruiting bodies ('cones') were consistent with those of the rare *Allocasuarina crassa* (Capes she-oak), a species known only from the Cape Pillar–Tasman Island area. However, the size of the trees — some with a diameter at breast height (dbh) in excess of 1 m and heights greater than 10 m — was clearly at odds with the original description of *A. crassa* as a 1–2 m high shrub (Johnson 1989). In addition, the flaky bark of the older specimens was quite unlike any of the recognised species of *Allocasuarina* in Tasmania.

Discussions with Dennis Morris of the Tasmanian Herbarium established that the specimens were indeed attributable to *A. crassa*, but that the original description required some revision to accommodate the features described above.

TAXONOMY

Allocasuarina crassa L.Johnson, Fl. Australia 3: 194 (1989)

Usually dioecious shrub or small tree, 0.3–12 m high, prostrate or erect habit. Bark smooth, becoming flaky with age. Branchlets spreading to ascending, to 26 cm long; articles 8–26 mm long, 0.75–4.0 mm diam., smooth, with densely pubescent furrows; phyllichnia strongly rounded; teeth 6–9 (–12), slender, spreading to slightly recurved, usually not overlapping, 1–4 mm long, not marcescent*. Male spikes occasionally moniliform, 1.0–4.5 cm long, 3.5–4 whorls per cm; bracteoles persistent; anthers 0.8–2.0 mm long. Cones long-cylindrical, sessile or on a peduncle to 3 mm long; cone body 15–52 mm long, 12–29 mm diam.; bracteoles obtuse to truncate, pyramidal protuberance slightly shorter than bracteole body. Samara 5–8 mm long, black. (*marcescent = withering without being shed)

Representative Specimens

Tasmania: Tasman Island, 26 September 1965, *J. Thwaites* (HO 92115)*; near Lunchtime Creek, Cape Pillar track, 14 April 1984, *A. M. Buchanan* (HO 77229); between the Blade and Cape Pillar, 4 December 1984, *P. M. Buchanan* (HO 92114); c. 9 km along track to Cape Pillar, just south of Corruption Gully, 22 February 1986, *K. L. Wilson* (HO 108752); Hurricane Heath, Cape Pillar, 13 June 1993, *F. Duncan* (HO 303938); Arthurs Peak, Tasman Peninsula, 26 April 1997, *R .B. Schahinger* (HO 321732); Tasman Peninsula, E of Arthurs Peak, 7 April 1998, *R. Schahinger* (HO 325433); 300 m WSW of Perdition Ponds (Cape Pillar), 28 April 1998, *R. Schahinger* (HO 512433); northern end of Tornado Flat (Cape Pillar), 28 April 1998, *R. Schahinger* (HO 512434); southern end of Corruption Gully (Cape Pillar), 28 April 1998, *R. Schahinger* (HO 512435). **(HO = Tasmanian Herbarium, Hobart)*

A comparison of original and revised characters based on an examination of fresh material from a variety of habitats in the Cape Pillar area is presented in table 1. The upper range of most of these characters has been increased considerably by the present study, though some of these differences — anther length, for example — may be attributable in part to Johnson's (1989) use of dried material.

NOTES

Two other species of *Allocasuarina* co-occur with *A. crassa* over the latter's range: the small tree *A. verticillata* (Lam.) L.Johnson on Tasman Island, and the shrub *A. monilifera* (L.Johnson) L.Johnson at Tornado Flat and Arthurs Peak (fig. 1). *Allocasuarina verticillata* can be readily distinguished from the other two species by its drooping foliage, pungent cones and hard fissured bark. *Allocasuarina crassa* is denser and coarser in appearance than *A. monilifera*, while it also differs from *A. monilifera* "in its larger and thicker articles with strongly pubescent furrows" (Johnson 1989: 159); *A. monilifera* has articles up to about 1 mm in diameter with glabrous furrows. Other differences are highlighted in a new key to the Tasmanian *Allocasuarina* species (appendix), developed in conjunction with Dennis Morris of the Tasmanian Herbarium in preparation for the revised edition of *The Student's Flora of Tasmania*.

PLATE 1

Tree-form of Allocasuarina crassa *with diameter at breast height of 1.07 m; note the flaky nature of the bark and the dense layer of needles at the base of the tree.*

PLATE 2

Habit of A. crassa *in a fire-protected slope near Tornado Ridge; two straight-trunked specimens right foreground, with a larger spreading specimen in background (trunk detail in pl. 1).*

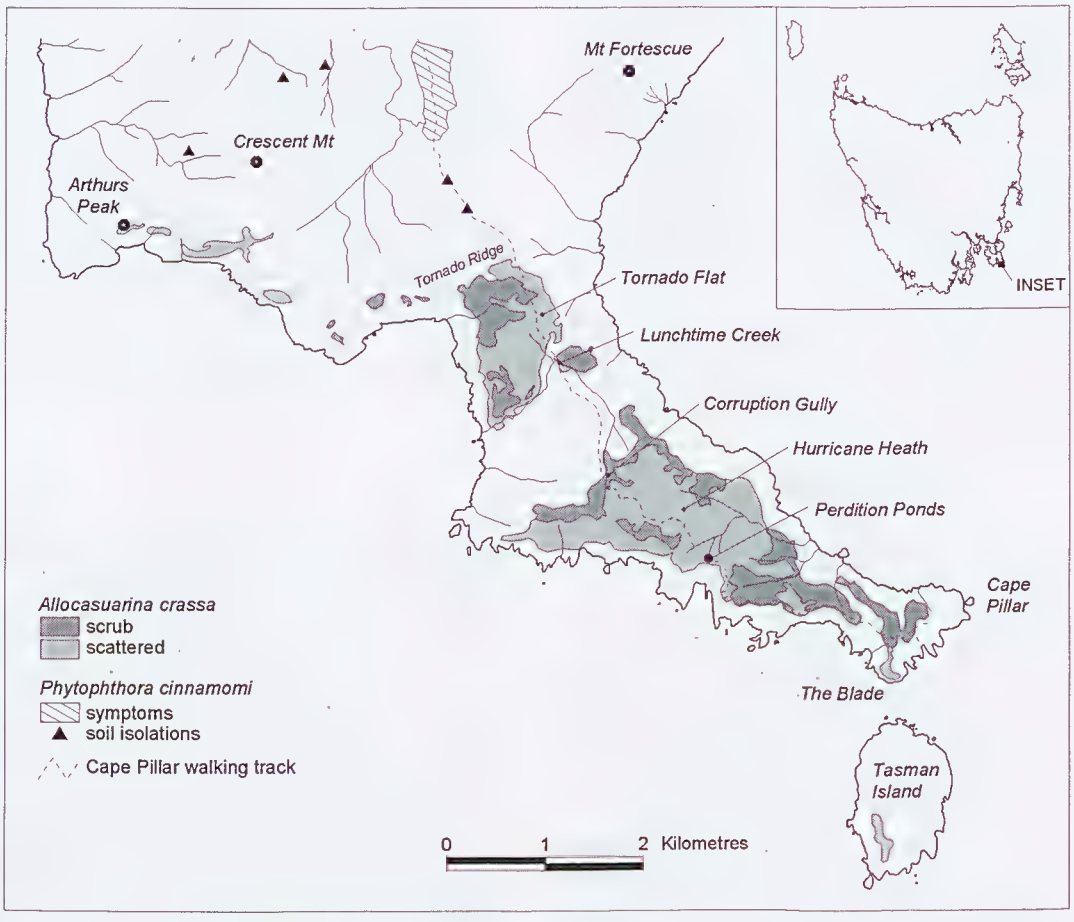

FIG. 1 — Distribution of Allocasuarina crassa *in Tasmania.*

TABLE 1
***Allocasuarina crassa*: original and revised characters**

Character	Johnson (1989)	Revised
habit	shrub, 1–2 m high	shrub to small tree, 0.3–12 m high
bark	smooth	smooth, aging to flaky
branchlets	to 17 cm long	to 26 cm long
articles	10–20 mm long, 1.2–2.0 mm diam.	10–26 mm long, 1.2–4.0 mm diam.
teeth	7–10, 1.1–3.0 mm long	6–12, 1.1–4.0 mm long
male flower spike	c. 2 cm long, rarely moniliform	1.0–4.5 cm long, occ. moniliform
anthers	0.8–1.0 mm long	0.8–2.0 mm long
cone body	15–34 mm long, 12–15 mm diam.	15–52 mm long, 12–29 mm diam.

DISTRIBUTION

Allocasuarina crassa is now believed to be confined to an area on the Tasman Peninsula between Arthurs Peak and Tasman Island (fig. 1). Surveys by the author during 1997–2001 showed *A. crassa* to be a common element of the dolerite cliff vegetation between Arthurs Peak and Tornado Flat, well removed from the species' previously recorded range. Walking south along the Cape Pillar track *A. crassa* is first encountered in *Eucalyptus tenuiramis/E. obliqua* damp forest just north of Tornado Flat, while on the Flat itself *A. crassa* occurs in closed heath/scrub. Further to the southeast *A. crassa* is a common component of the vegetation of the Cape Pillar plateau, and indeed dominates some areas. *Allocasuarina crassa* attains tree stature in a number of sheltered sites along the walking track, e.g., Lunchtime Creek in conjunction with *Callitris rhomboidea* (Oyster Bay pine), the southern end of Corruption Gully, and between The Blade and Cape Pillar (fig. 1). The species is also locally common on the southwestern corner of the Tasman Island plateau in dry heath and scrub.

HABITAT

Allocasuarina crassa ranges from a prostrate shrub growing on the windswept rocky slopes southwest of Perdition Ponds (pl. 3), through the more 'typical' shrub form found in heaths, to a shrub or small tree on the exposed southerly-facing dolerite cliffs between Arthurs Peak and Cape Pillar (pl. 4), to the tree form described earlier in more sheltered areas.

The main stems of the Perdition Ponds plants are typically ground-hugging, with branches erect to about 30 cm, and articles up to 4 mm in diameter. The cones are relatively squat and well hidden within the plant, while branchlets have a conspicuously striped appearance due to the dense pubescence of the article furrows and the glabrous article ridges (pl. 5).

At the other extreme, articles with diameters of little more than 1 mm are present on tree-form specimens in the sheltered Corruption Gully area. Such an article size is comparable to that of *A. monilifera*, though the presence of strongly pubescent article furrows is again consistent with *A. crassa*. The flaky bark associated with the tree form of *A. crassa* would seem to be purely a function of age, as evidenced by the range of specimens shown in plates 1 and 2.

CONSERVATION STATUS

Allocasuarina crassa is currently listed as rare in the Tasmanian *Threatened Species Protection Act 1995*. The taxon continues to qualify for rare under criterion B of the Act, viz., "Species subject to stochastic risk of endangerment because of naturally small population size (extent of occurrence < 2000 km^2)". Population characteristics are: (1) linear extent: 10.2 km, (2) extent of occurrence: 20 km^2, (3) area of occupancy: ~ 400 ha, (4) number of mature individuals: (O) 100,000. The taxon has been found only in the Tasman National Park in southeastern Tasmania.

A number of *A. crassa* plants may have been destroyed during vegetation clearance on Tasman Island in the early 1900s when the Tasman lighthouse was built. Since the de-manning of the lighthouse in 1977 — and the subsequent cessation of slashing and of grazing by sheep — the vegetation has begun to re-establish itself, and *A. crassa* is now present in significant numbers. However, ongoing threats to *A. crassa* over its entire range include an inappropriate fire regime, and death through infection by the exotic soil-borne plant pathogen *Phytophthora cinnamomi*.

Barker (1994) found that *A. crassa* was moderately susceptible to *P. cinnamomi* in laboratory conditions and, given *A. crassa's* localised distribution, considered a "vulnerable" status to be more appropriate than "rare". The Tasmanian Parks and Wildlife Service established a washdown point at Lunchtime Creek on the Cape Pillar walking track in line with Barker's recommendations, ostensibly to restrict the movement of *P. cinnamomi* from known infestations to the Cape proper (fig. 1; with protection of *A. crassa* and the susceptible endemic shrubs *Epacris marginata* and *Epacris myrtifolia* in mind). *Allocasuarina crassa* has yet to display symptoms of *P. cinnamomi* infection in the field (as at May 2002), and while these observations are comforting, the rarity of the species does mean that the present precautionary approach to walker hygiene on the Cape should be maintained.

Allocasuarina crassa is a serotinous species, storing its seed in cones in the canopy until fire causes its release. Most of the *A. crassa* scrubs observed on Cape Pillar are even-aged, with little sign of continuous recruitment (Rollins 1999). If an area happened to be burnt and then burnt again before plants had time to produce fruit, then *A. crassa* could be eliminated. This scenario is considered to be extremely unlikely, however, because of *A. crassa's* presence

PLATE 3
Prostrate A. crassa *on the rocky exposed slopes to the south-west of Perdition Ponds, Cape Pillar.*

PLATE 4
Shrub-form of A. crassa *on the cliff-tops to the east of Arthurs Peak, with Mt Brown and Cape Raoul in the background.*

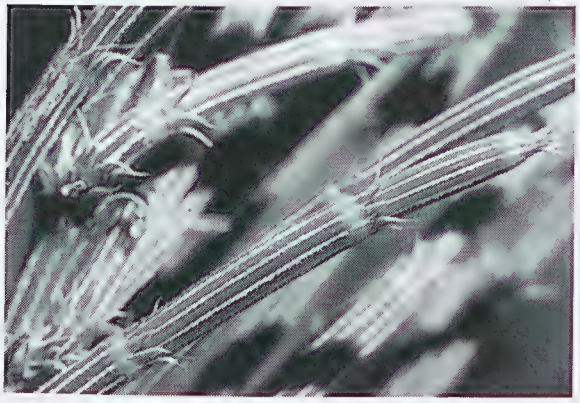

PLATE 5
Detail of A. crassa *branchlets showing the distinctive pubescent article furrows and long spreading 'teeth'.*

in such a variety of habitats, including numerous fire-protected niches in the rugged dolerite cliff-faces that bound the Cape. Indeed, it is worth noting that much of the Cape has not been burnt for decades, some areas possibly not for centuries. In the late 1970s, however, a fire did burn about 60 ha of heath and scrub in the Perdition Ponds area, including 10 ha of scrub previously dominated by *A. crassa* (pl. 6); recovery has been very slow in this exposed area, with areas formerly supporting tall scrubs now reduced to 1.0–1.5 m heaths.

DISCUSSION

The disparate forms of *A. crassa* observed in the Cape Pillar area — that is, prostrate shrub to small tree — can be interpreted as a simple response to differing environmental pressures. Variables such as fire history, degree of exposure, topography, drainage, soil depth and fertility have combined to produce a diverse range of microhabitats (Brown & Duncan 1989), with species' growth patterns responding accordingly. Indeed, both *Banksia marginata* (Honeysuckle) and *Leptospermum scoparium* (Manuka or Tea-tree) display similar variability in the Cape Pillar area.

What makes *A. crassa* noteworthy is its capacity to dominate vegetation on much of the Cape Pillar plateau. Given an extended period without fire, say 60–80 years, *A. crassa* may form almost monotypic low forests; such areas can be readily mapped from aerial photographs due to their dark signature (pl. 6). The ground beneath these forests tends to be blanketed with a thick carpet of she-oak needles (pl. 1), and in consequence the ground layer is sparse and species-poor. The stand of *A. crassa* represented by the massive specimen shown in plate 1 most likely represents a successional endpoint in the continued absence of fire. Contributing factors include the site's southeasterly aspect and the development of a buffer of predominantly broad-leafed species — species such as native laurel (*Anopterus glandulosus*), dragon heath (*Richea dracophylla*), dogwood (*Pomaderris apetala*) and stinkwood (*Zieria arborescens*) — between the *A. crassa* trees and the adjacent pyrogenic eucalyptus-dominated forests. An analogous situation exists in the lee of nearby Crescent Mountain (fig. 1), where a small patch of relict rainforest dominated by myrtles (*Nothofagus cunninghamii)* has survived.

The *A. crassa* low forests on the Cape Pillar plateau occupy areas that are relatively well-drained. *Leptospermum glaucescens* (soft-fruited tea-tree) may co-dominate with *A. crassa* in sandier areas (along with sub-dominants *Banksia marginata* and *Leptospermum scoparium*), and may dominate completely in some areas due to its ability to grow faster and taller than other large shrub species (Kirkpatrick & Harris 1999). A 50-year fire-free period could see the greater proportion of the Cape Pillar plateau dominated by just these two species; the active use of fire for ecological purposes by the managers of the Tasman National Park will inevitably be a lively topic for discussion in the not too distant future.

ACKNOWLEDGEMENTS

Many thanks to Dennis Morris, Alex Buchanan and Andrew Rozefelds of the Tasmanian Herbarium for their assistance during the evolution of this paper, with particular thanks to

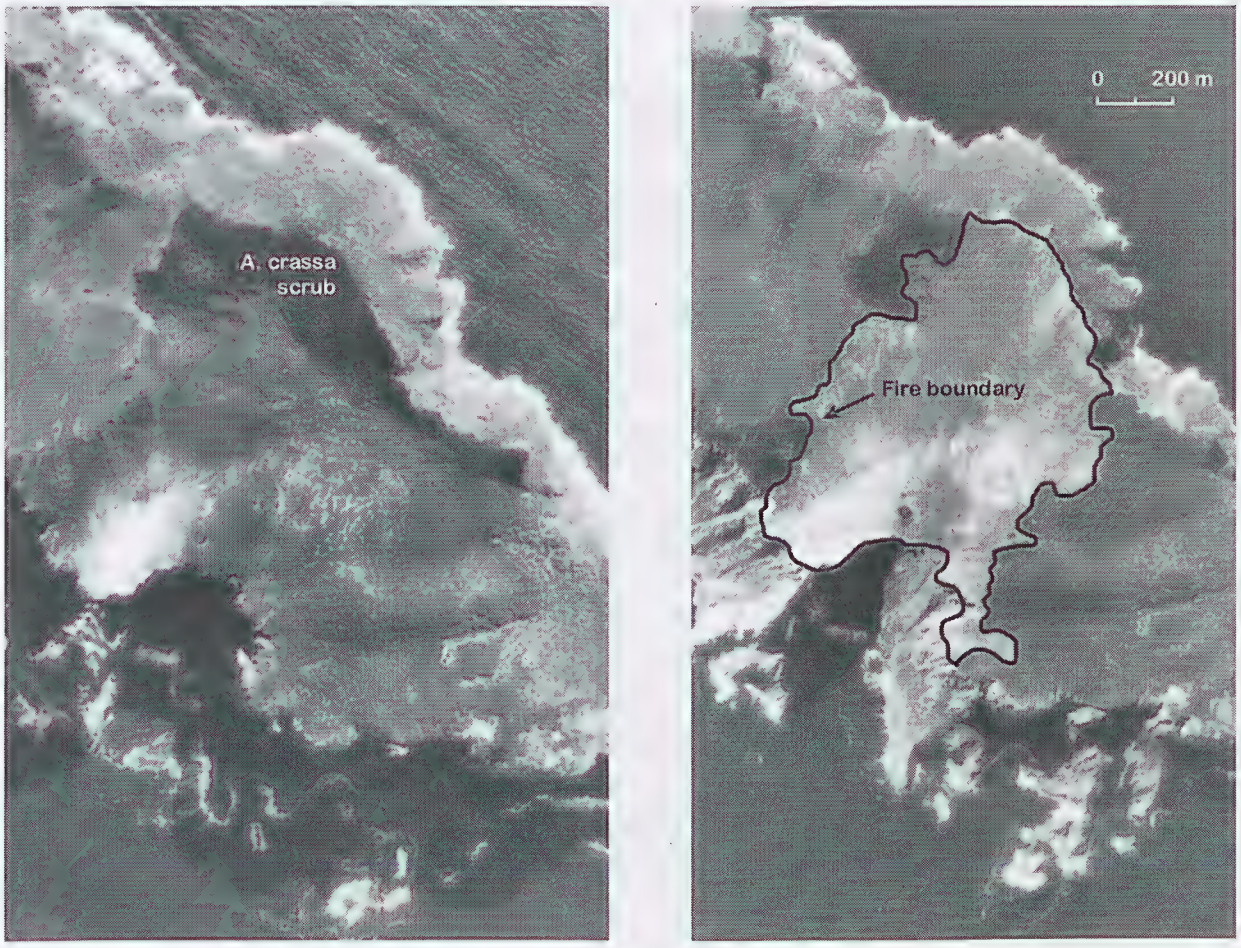

PLATE 6

Aerial photographs of the Perdition Ponds area showing scrubs dominated by A. crassa *and the impact of fire; left panel, 18 April 1975, right panel, 28 February 1980.*

Dennis Morris for allowing the use of the key to the Tasmanian *Allocasuarina* species.

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(accepted 9 December 2002)

APPENDIX

Key to the Tasmanian *Allocasuarina* species (Morris, in prep.)

1 Branchlets strongly drooping, minutely roughened; articles 8–40 mm long, furrows pubescent; cones cylindric to almost globular; cone valves prominent, their margins along the line of opening pungent-acute ..... *A. verticillata*
Branchlets ascending or drooping; smooth; articles up to 26 mm long, furrows pubescent or glabrous; cones ovoid to cylindric; cone valves with margins along the line of opening rounded or bluntly pointed 2

2 Phyllichnia with a median groove along their length; furrows occasionally minutely pubescent; shrub local in the northeast ..... *A. paludosa*
Phyllichnia rounded or angular, without a median groove; furrows pubescent or glabrous 3

3 Article furrows densely to sparingly pubescent 4
Article furrows usually glabrous, occasionally sparingly pubescent in basal articles of the branchlets 5

4 Shrub or small tree to 15 m high; articles 3–10 mm long, 0.4–1.0 mm in diameter; teeth 6–8, 0.3–0.9 mm long, appressed to slightly spreading; bark fissured; widespread in northern and eastern Tasmania ..... *A. littoralis*
Shrub or small tree to 12 m high; articles 8–26 mm long, 0.75–4.0 mm in diameter; teeth 6–12, 1–4 mm long, spreading or recurved; bark smooth or flaky; restricted to the Cape Pillar and Tasman Island area of the Tasman Peninsula ..... *A. crassa*

5 Usually monoecious shrub 1–5 m high; articles usually 5–9 mm long, teeth 5–10 ..... *A. monilifera*
Usually dioecious shrub or tree to 8 m high; articles up to 18 mm long, teeth 7–9 6

6 Usually erect ± fastigiate small tree to 8 m high; cones 1.5–6.0 cm long; restricted to dolerite substrates in the Wellington Range, Snug Tiers and Bruny Island ..... *A. duncanii*
Usually ± spreading shrub to 6 m high; cones 1–3 cm long; King Island, western Tasmania and the Central Highlands ..... *A. zephyrea*

Terminology (after Johnson 1989): the branchlets of *Allocasuarina* species are articulate, with several short basal articles and 1–numerous elongated articles. 'Teeth' refer to the reduced leaves at the apex of each branchlet article (see pl. 5). Each article has as many ridges (phyllichnia) as there are teeth; the phyllichnia are separated by furrows that may be obviously pubesecent or glabrous.

A BARREN PART OF THE MAIN?: THE VEGETATION OF HUNTER ISLAND, FLEURIEU GROUP, BASS STRAIT

by Stephen Harris and Eve Lazarus

(with one table, five text-figures, ten plates and three appendices)

HARRIS, S. & LAZARUS, E., 2002 (31:xii): A barren part of the main?: the vegetation of Hunter Island, Fleurieu Group, Bass Strait. *Papers and Proceedings of the Royal Society of Tasmania* 136: 107–126. ISSN 0080–4703. Nature Conservation Branch, Department of Primary Industries, Water and Environment, GPO Box 44, Hobart, Tasmania 7001, Australia.

Hunter Island, visited over millennia by Aboriginal people and settled early in the nineteenth century by sealers and later by a succession of grazing lessees, has preserved in its vegetation pattern the effects of a long history of firing and clearing. The vegetation also reflects the substrate and topographic features of the island with a major dichotomy between the heaths and scrub on the highly acid quartzites that underlie most of the island, and woodlands and grasslands on the highly alkaline sands that are rafted onto its western part.

Eucalyptus viminalis occurs on alkaline sands on Hunter Island, in contrast to the absence of the species on calcareous coastal sands in the rest of its range in southeastern Australia. Heathlands make up 38% and scrub 37% of the island. Other vegetation types recorded are swamp forests, button grass moorland, exotic and native grasslands, *Eucalyptus viminalis* woodland, wetlands, mutton-bird rookery vegetation and lichen-fields.

The flora has strong affinities with the northwestern coast of the Tasmanian mainland and a weaker affinity with Three Hummock Island, which is a granite island rather than a quartzite one. A Bassian floristic element occurs on the alkaline substrates; however, it is not as strong as that in the island flora of eastern Bass Strait. The flora and vegetation have components that are significant for nature conservation such as remnant *Eucalyptus viminalis* stands on the sands. The species of conservation significance include rare and threatened species: *Pterostylis cucullata, Calochilus herbaceous, Cyrtostylis robusta, Parietaria debilis, Ranunculus amphitrichus* and *Cotula vulgaris* var. *australasica.*

Key Words: flora, vegetation, fungi, Fleurieu Group, Bass Strait, island, human impact, Conservation Area, conservation, rare and threatened species, weeds, environment history, cattle-grazing impact, International Biodiversity Observation Year 2001–2002.

INTRODUCTION

Hunter Island, at 7064 ha, is the largest island in the Fleurieu Group off northwest Tasmania. The island is separated from Cape Grim, off the northwestern tip of Tasmania (fig. 1), by the shallow Hunter Passage, which is only 6 km wide. Formerly known as Barren Island, Hunter Island is situated at 40°34'S and 144°45'E. It is about 24 km long and between 0.5 km and 6.5 km wide.

The island's low altitude, numerous shoals, smaller outlying islands, shallows and strong tidal currents meant it was given a wide berth by the earliest maritime explorers since the island was first observed by Matthew Flinders on his circumnavigation of Tasmania. His fellow officer, Bass, described the island as a "pointed part of the main, which in height and starved vegetation very much resembled Three Hummock Island" (Flinders 1801).

The island became renowned in the 1970s for an important archaeological site at Cave Bay Cave and other sites on the island (Bowdler 1974, 1980, 1984), which established that there had been more or less continuous use of the islands by humans since 23 000 years BP. Hope (1978) reconstructed a vegetation history of the island as a background to human occupation. Pollen analysis showed that the island has had similar open shrubby vegetation throughout the Holocene with fires occurring in both occupied and unoccupied phases. Cold steppe vegetation in this area during the Pleistocene was part of a contiguous expanse of open grassland and scattered trees extending from this part of Bass Strait to the Adelaide region. Hope summarised the present vegetation of the island but remarked on the lack of any botanical survey.

Wider systematic vegetation surveys have included Hunter Island and have dealt with particular vegetation types such as heathlands (Kirkpatrick 1977, Kirkpatrick & Harris 1999), coastal vegetation (Kirkpatrick & Harris 1995) and wetland vegetation (Kirkpatrick & Harwood 1981, 1983a, b). While these surveys are aimed at statewide overviews, they have contributed a valuable context for more comprehensive work. No overview of the vegetation ecology of the island has been attempted. Davies (1981) sampled the vegetation of a portion of the coast between Ainslie Beach and Shepherds Bay, sites that were predominantly heathland at that time.

The aims of this study were to describe the current vegetation, make an inventory of vascular plant species and carry out a reconnaissance of the macrofungi. Additionally, we aimed to investigate the principal ecological factors determining vegetation pattern, to assess the conservation significance of the flora and vegetation and to make recommendations on the vegetation management of the island. This study forms part of a wider survey of the flora of the lesser-known coasts and islands of Bass Strait — a project included in the program of the International Biodiversity Observation Year 2001–2002.

METHODS

This study is based on one visit by both authors to the island between 9 and 19 October 2001, during which 83 km of foot transects were conducted to cover the major variations in habitat, and a further brief visit by one of us between 3 and 5 June 2002.

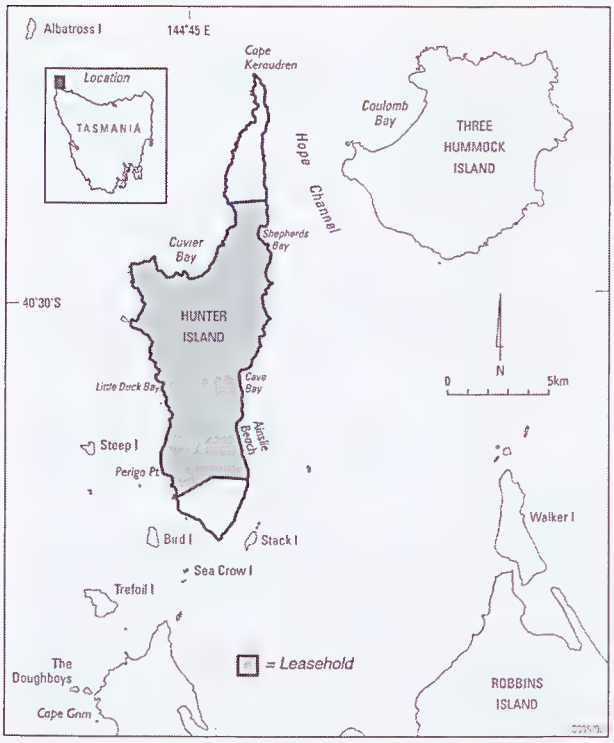

FIG. — 1. Locality of study area.

Information on the geology, soils and climate was synthesised from various published and unpublished sources to provide an environmental context for our vegetation studies. Existing sources were interpreted and supplemented by aerial photograph interpretation of landforms and field observations.

The history of grazing and occupation of the island was assembled through primary and secondary sources. Historical information was supplemented by an examination of earlier black and white aerial photographs dating from 14 January 1968 and 8 January 1980.

Forty-seven plots measuring 10 x 10 m^2 were located to sample variations in habitat. Location of the plots was according to the 'subjective without preconceived bias' approach of Mueller-Dombois & Ellenberg (1974). Species presence/absence, vegetation structure, soil pH, texture and colour, rock type, fire history and geographical features such as aspect, altitude, topography, drainage and grid reference, were recorded in each plot.

A vascular plant species list was compiled and the voucher specimens of most species were lodged in the Tasmanian Herbarium (HO). A search of the National Herbarium of Victoria (MEL) and the National Herbarium of New South Wales (NSW) was made for specimens from the island. Species occurring on the island were assessed for their nature conservation significance. High levels of rainfall during the October expedition to Hunter Island provided an opportunity to collect several species of macrofungi for identification. Due to the season in which collection was undertaken, the number of specimens was fewer than would be found in the autumn months. The inclusion of a mycological species list in this report is an effort to establish a baseline of information (see recommendations in Scott *et al.* 1997). Where possible, all fungi identifications are supported by colour photographs of fresh specimens, comprehensive descriptions and voucher specimens in herbaria.

Photo-communities were mapped from full-colour aerial photographs dated 1 January 2001, which had been enlarged to 1:26,000. These photo-communities were checked in the field and, where possible, were allocated to TASVEG statewide mapping communities.

Other observations along the transects were used to supplement the plot information and assist in interpreting the vegetation ecology.

Floristic communities were identified by hand sorting of the plot species lists. Species lists from quadrats collected by Wells (see Kirkpatrick & Harris 1995) and Davies (1981) and Kirkpatrick & Harwood (1981) were used to inform the analysis of vegetation types of the island. Records of species by these authors are annotated in our consolidated species list for the island.

Plant nomenclature follows Buchanan (2002) for vascular species except where authorities are given. Macrofungi nomenclature follows *Fungi of Australia*, Volume 1A (Australian Biological Resources Study 1996). Conservation and reservation status of species and communities was assessed against published lists and the schedules to the Tasmanian *Threatened Species Protection Act 1995*.

RESULTS

Physical Description: Geology, Soils and Climate

Geological reconnaissance of the island (Jennings & Sutherland 1971) has demonstrated that the island comprises a north–south trending anticline of orthoquartzites and siltstones. The physiography of the island is strongly controlled by the bedrock structure, especially notable along parts of the coast; for example, east of Cape Cuvier where a series of beaches are separated by quartzite ridges and headlands trending conformably with the strike of the anticline.

The island rises to about 60 m above sea level where a plateau is formed that runs north–south. The highest point is a knoll just over 80 m above sea level and situated at latitude 40°28'45", longitude 144°46'40". Calcareous sand sheets have been blown up on to the western side of the island. Behind Shepherds Bay (see pl. 1) the sand sheet and dune systems bisect the island from west to east. Due west of Ainslie Beach, the quartzite plateau surface is transgressed by the leading edge of a large parabolic dune system.

There are few identifiable surface creeks on the island and surface drainage is otherwise very confused. The drainage is mostly sub-surface where the calcareous sand sheets occur — drainage to the west off the higher quartzite ridge would flow as groundwater towards the west coast where there are numerous coastal bogs, swamps and springs. Some lagoons and swamps occur on the inland margins of the sand sheet where the surface drainage off the quartzite ridge has been impeded. About three streams drain off the quartzite to the east coast and one stream drains to a small beach on the southwest coast. An excellent series of Holocene beach ridges occurs behind Ainslie Beach. Robin & Parsons (1976) reported such a series of dune ridges at Westernport Bay in Victoria, suggesting they may be an excellent resource for vegetation and soil succession chronosequence work. Like those at Westernport Bay, the Holocene beach ridges on Hunter Island have a vegetation pattern that has been degraded by fire history and stock

PLATE 1

View to the northern end of Shepherds Bay beach. The ridge consists of an old stable dune over a quartzite base, the quartzite being visible only around the shoreline. Calcium carbonate is leached from the alkaline dunes and precipitated as rimstone pools around the high watermark on the rocky shore. The dune vegetation comprises Leptospermum laevigatum, Banksia marginata, Acacia longifolia *subsp.* sophorae, Leptospermum glaucescens *and* Acacia mucronata.

grazing However, the soil development chronosequence may be intact and of potential scientific importance. Lagoons of up to 23 ha occur over the island.

Soils on the quartzite substrates are commonly grey acid (usually pH 4.5) sandy loams but in consistently wet areas peats have formed (table 1). Bedrock is exposed in many areas, where only skeletal soil occurs. On the sand sheets the brown loamy sands are highly alkaline (pH 9) and very friable. An organic horizon occurs on these where a long fire-free period has occurred. The soils under the lagoons are peat.

The island is in the warm humid zone (Gentilli 1972), characterised by a mean annual rainfall of about 900 mm (based on records between 1961 and 1994). Rain falls throughout the year and the rainfall pattern is probably very similar to nearby Three Hummock Island, which has a monthly maximum of more than 220 mm in July and a minimum of 10 mm in February. The temperature is mild throughout the year with daily average temperature ranges of 13°–20°C in February and 8°–12.9°C in July (Bureau of Meteorology 1996). The west coast receives the full impact of the westerly ocean swells. The east coast is more sheltered.

Historical Accounts of Vegetation and Habitat

Matthew Flinders and his crew were the first Europeans known to sight the islands. He assumed that Hunter Island, which he called Barren Island, may have been a part of the mainland of Tasmania. His observation of the island as having "... starved vegetation" (Flinders 1801) and his naming of it Barren Island indicate the vegetation structure may not have been all that much different from today. Howie's comment in 1838 (Howie cited in Buckby 1989) to the effect that the island was "perfectly treeless" and a "kind of scrub overruns its surface" adds extra confidence to this assumption.

On his circumnavigation of Tasmania Kelly met Aborigines occupying the southern part of Hunter Island but it is not clear whether they intermittently visited the island or whether they were a resident band (Kelly cited in Bowdler 1981). Their presence in any case would explain the stature of the vegetation, as fire was a commonly-used instrument for keeping the land open and accessible as well as promoting new growth for macropods.

Hunter and Three Hummock islands were the only areas in Bass Strait to be occupied by humans at the time of European contact. The impact of traditional firing practices was thus continuous on the island for as long as it was on northwest Tasmania.

TABLE 1
Soil properties of the vegetation types of Hunter Island

Vegetation community	Soil type	pH	Colour	Drainage
Heathlands	sandy loam	4.5	5YR 2.5/1	good
Swamp forests	peat	8.0	7.5YR 2.5/1	poor
Button grass moorland	peat	4.5	2.5YR 2.5/1	poor
Exotic grassland	sandy loam	8.5	10YR 3/2	excellent
Grassland	loam	6.5	2.5YR 2.5/1	excellent
Eucalyptus viminalis Woodland	calcareous sand	8.5	2.5YR 3/2	excellent
Wetlands (i)	calcareous sand	6.5-8.0	no record	poor
Wetlands (ii)	sandy loam	4.5	no record	poor
Wetlands (iii)	peat	4.5	no record	poor
Scrub community (i)	sandy loam	4.5	10YR 3/1	good
Scrub community (ii)	sandy loam	6.0	10YR 2/1	good
Scrub community (iii)	loam	9.0	10YR 2/2	good
Scrub community (iv)	loam	8.0	7.5YR 2.5/1	poor
Scrub community (v)	sandy loam	4.5	7.5YR 2.5/1	good
Mutton-bird rookeries	sandy loam	9.0	7.5YR 3/2	excellent

Under the guidance of G. A. Robinson, a settlement was made on the east coast, probably near Ainslie Beach (Bowdler 1980) for use as a concentration camp for Aborigines in 1832. After a short time the camp moved to the west coast, presumably because of the more abundant marine food resources (O'Connor 1982) and also, we suggest, because of the suitability of the grassy *Eucalyptus viminalis* forests for camping.

In October 1837 Ronald Gunn visited the island and collected some plants. In the following year, the island was mentioned in a letter from Howie, resident on King Island, to the then Surveyor-General. He stated "Hunter Island well deserves its former name of Barren, for it is perfectly treeless; a green kind of scrub overruns its surface, which at its highest point is three hundred feet above the level of the sea". Howie was applying for occupation of an area at Cuvier Bay in 1838. This was the same year that HMS *Beagle* was carrying out hydrographic survey work in the vicinity. Lieutenant Stokes in fact, walked on the plateau to get bearings on coastal features. One of his assistants referred to accompanying Stokes "over dreadful brushwood summits" (Hordern 1989).

The use of the island for grazing purposes began in the 1850s when Dr James Grant was granted a lease in 1853. In 1860 a report on the island suggested that "Hunters Island well suited for cattle, and also well watered; these islands will carry a large number of cattle — from 500–1000 head each. Sheep will not do from the presence of the cotton plant". The occupation of the island by lessees for cattle grazing has been more or less continuous since (Buckby 1989).

This grazing period, which has persisted to the present day, has had a large impact through clearing of the vegetation on the calcareous sands, and the sowing of exotic pasture species. Implicit in a letter written by the lessee of the island in 1870, is a landscape with dense native tussock grasses and no exotic pasture: "Up to the present time we have made a very heavy loss, the grasses being too rank for fattening. The only chance of making the place pay would be by spending a considerable amount on improvements, English grasses etc." (cited in Buckby 1989: 47). Introduced garden and ornamental plants have been established around the house site but these have not spread (pl. 2).

Most of the island is presently held under a grazing lease comprising 6980 ha (fig. 1). While there are cattle confined to paddocks, there is also an undetermined number that are feral and these are presently to be encountered throughout the island (pl. 3). The observed impacts of the feral cattle include pugging of soaks and wetland margins, physical damage to beach dunes and physical damage to scrub understorey in the vicinity of camps.

PLATE 2

The main homestead on Hunter Island is sheltered by Cupressus macrocarpa. *The house is surrounded by many ornamental and garden plants including* Cordyline australis, Agapanthus, Prunus *and* Hydrangea.

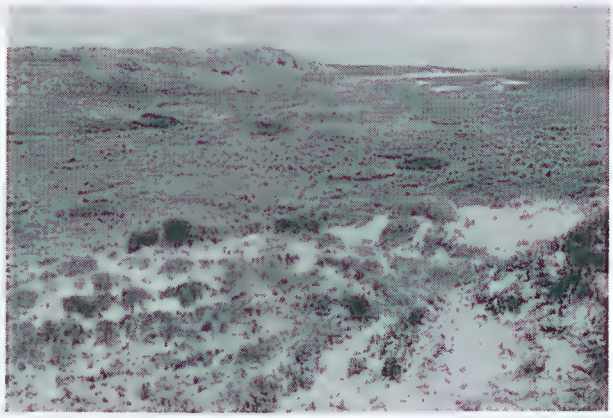

PLATE 3

Looking south on the west coast towards Perigo Point. The exotic pasture is interrupted by Poa *tussocks and colonies of* Isolepis nodosa. *In the right foreground cattle have heavily grazed a sward of* Lepidosperma gladiatum. *A tongue of sand in the near distance has been colonised and stabilised by* Ammophila arenaria.

The Vegetation

Heathlands

Heathlands are the most extensive vegetation formation on the island, covering 2672 ha or 38% of the island. The heaths are maintained by fire on shallow well-drained sandy loams over quartzite basement. Heath also occurs on some localised accumulations of sand. Species richness is fairly uniform throughout the heathlands with mean vascular species diversity in 10 x 10 m^2 plots of 18 species and the maximum recorded for a plot being 30 species.

Three different floristic communities were identified, each of which fits three different heath types (defined in Kirkpatrick & Harris 1999). The most extensive of these is the soft-fruited dry heath represented by various facies of floristic community 26. These heaths occur widely on the plateau surface. In some sites, *Eucalyptus nitida* forms coppices and occurs in an open shrub layer up to 2.5 m high, co-dominant with *Leptospermum glaucescens, Acacia mucronata* and *Banksia marginata.* In some sites the emergent shrubs may be only 50 cm over a heath layer of 20–30 cm. In the latter sites the last fire was two to three years ago whereas the site example with the 2.5 m shrub layer was previously burnt 24 years ago.

Commonly occurring species in the island quadrats for this heath type include *Leptospermum glaucescens, Banksia marginata, Epacris impressa, Aotus ericoides, Dillwynia glaberrima, Allocasuarina monilifera* and *Lepidosperma concavum.*

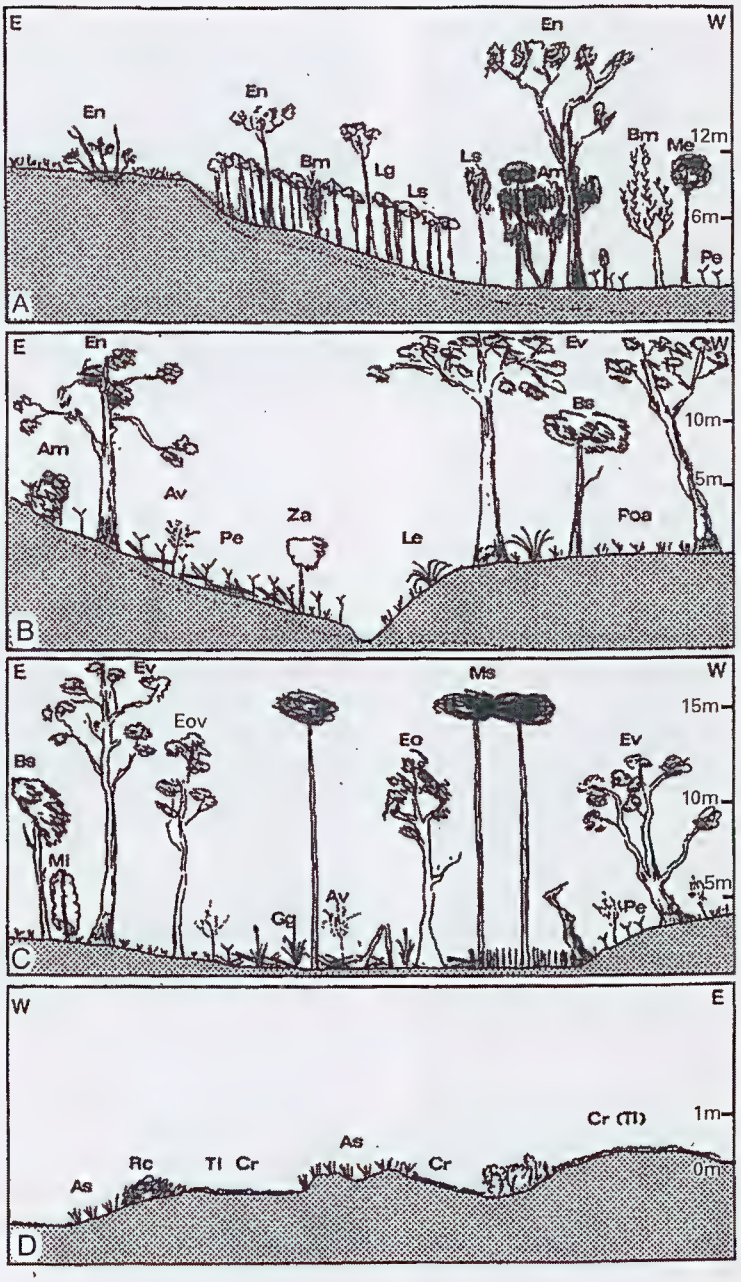

FIG. 2. — Profile diagrams showing the nature of some vegetation boundaries.
(A) The western margin of the plateau surface is marked by a typically abrupt transition from heathland and shrubland to scrub and forest. The depth of soil increases to the west and the fire frequency decreases from the plateau heathland to the forest. The form of Eucalyptus nitida *changes across the profile – coppiced mallee-form specimens on the plateaus to tall single-stemmed trees in the forest.*
(B) The dramatic boundary between lower pediment slopes of the plateau on the left and the toe of the old alkaline sand sheet on the right is marked by a narrow creek-line. To the east is shrubby Eucalyptus nitida *forest on shallow acid soils and west of the creek-line is well-developed grassy* Eucalyptus viminalis *(*Bursaria spinosa*) forest on the deep alkaline soils.*
(C) A Melaleuca squarrosa *swamp occupies a low flat on the alkaline sand sheet. The higher ground is occupied by* Eucalyptus viminalis *(*Eucalyptus ovata*) forest.*
(D) Cape Keraudren is fully exposed to westerly weather and has large salt loads dumped on it. This profile demonstrates the low-pruned shrubberies, succulent mats and salt-hardy grasses that make up the vegetation mosaic on the cape.

Plant symbols: Am = Acacia mucronata, *As* = Austrostipa stipoides, *Av* = Allocasuarina verticillata, *Bm* = Banksia marginata, *Bs* = Bursaria spinosa, *Cr* = Carpobrotus rossii, *En* = Eucalyptus nitida, *Eo* = Eucalyptus obliqua, *Eov* = Eucalyptus ovata, *Ev* = Eucalyptus viminalis, *Gg* = Gahnia grandis, *Le* = Lepidosperma elatius, *Lg* = Leptospermum glaucescens, *Ls* = Leptospermum scoparium, *Me* = Melaleuca ericifolia, *Mi* = Myoporum insulare, *Ms* = Melaleuca squarrosa, *Pe* = Pteridium esculentum, *Poa* = Poa *spp*, *Rc* = Rhagodia candolleana, *Ti* = Tetragonia implexicoma, *Za* = Zieria arborescens.

Floristic community 67, scented paperbark wet heath, is almost as abundant as the previously described community. This vegetation community is found on poorly-drained acid peat (pH 4.5) or acid sandy loams, of variable depth. The sites sampled were sedgy heaths in one case with *Leptospermum glaucescens* emergent at 60 cm. Common species recorded in this heath type included *Leucopogon australis, Melaleuca squamea, Pultenaea dentata, Aotus ericoides, Epacris lanuginosa, Epacris impressa, Drosera peltata, Boronia citriodora* and *B. parvifolia.* There have been fires in this heath type in the last two to three years. At two sites there is evidence of fire having occurred about 27 years and 15 years respectively prior to the most recent burn. On the site with the 27-year fire interval, the vegetation had grown into a 3 m high scrub with a high component of *Banksia marginata* and *Leptospermum scoparium.*

Swamp paperbark dry heath was sampled by recording species assemblages approximating floristic community 3. This type occurs on well-drained acidic soils on the central eastern plateau of the island. The soil profile has a peaty or loamy A-horizon. This community is more likely to be floristically closer to a scrub community than to some of the other heath communities. That is, in the absence of fire, this type would revert more rapidly to scrub than some other heath communities.

Swamp forests

Swamp forests make up only 34 ha or 0.5% of the island. They occur on deep, peaty soils on the leading edges of the alkaline sand sheets. These Pleistocene sand sheets, blown onshore from the west, have ponded the drainage coming off the topographically higher quartzite plateau and ridges. Depending on the topography of the bedrock basement, some groundwater drainage may be directed from the sand sheets to the swamps.

The swamp forests are dominated by *Melaleuca squarrosa* up to 20 m high; they form dense apparently even-age stands over an understorey dominated by *Carex appressa* and *Gahnia grandis.* In one locality a tall blackwood (*Acacia melanoxylon*) was observed; in another *Eucalyptus obliqua* up to 10 m high was noted. Both these trees are rare on the island and are likely to be relicts of more extensive stands. Their occurrence at trace levels prompts the question of whether fire frequency became inimical to their survival. In the swamp forest where the canopy has been broken (fig. 2C), there is extensive tree-fall and the dense scrubby layer comprises *Gahnia grandis, Acacia verticillata* subsp. *verticillata, Pimelea* sp. and *Urtica incisa.* Wind may be the cause of the broken canopy in the swamp forest. While the canopy of such closed forests remains intact, wind flow is smooth but as soon as the canopy surface is opened a small amount wind turbulence increases and breaks down the forest.

The swamp forest observed by us falls into the depauperate tea-tree scrub forest type (Pannell 1992). This community occupies better-drained sites than those of other swamp forest types. In some areas sampled by Kirkpatrick & Harwood (1983a, b) the forests tend to be dominated by *Melaleuca ericifolia,* with *Carex appressa* and *Gahnia grandis* present as understorey species. These would fit the depauperate tea-tree/paperbark scrub forest type. Examination of aerial photographs in a sequence from 1968, 1980 and 2001 indicates that small patches of depauperate tea-tree scrub forest have survived intact through 30 years of very high fire frequency. In the absence of fire it is conceivable that the diminutive *Melaleuca ericifolia*/*M. squarrosa* scrubs fringing many of the smaller lagoons on the quartzite substrates would develop into tall scrub and low closed forest.

Button grass moorland

The patch of button grass *(Gymnoschoenus sphaerocephalus)* moorland on Hunter Island falls into the Eastern Moor (Lowland form) type (Jarman *et al.* 1988). Its floristic composition best fits the category Common West Eastern Heath (ElCa) in the classification by Jarman *et al.* (1988). The patch occupies a poorly-drained saddle between rises on the highest part of the quartzite plateau and covers about four hectares on peat more than 30 cm in depth. The saddle gently slopes to the west and is exposed to the predominant weather direction. The button grass hummocks are well-developed and cover 40% of the site with a sedgy heath occupying the remainder. The species we recorded included the graminoids *Hypolaena fastigiata, Thelionema caespitosa* and *Empodisma minus;* shrubs *Sprengelia incarnata, Epacris impressa, Dillwynia glaberrima, Hibbertia riparia, Boronia parviflora, Melaleuca squamea, Epacris lanuginosa* and *Bauera rubioides;* and ferns *Lindsaea linearis* and *Selaginella uliginosa.* Emergent shrubs of *Banksia marginata* and *Leptospermum scoparium* up to 1.6 m high occupy about 5% of the site. The site appears to have been frequently burnt with the previous fire being about six years ago and a fire about 18 years before that. This is the only known button grass site on any of the islands in western Bass Strait (pl. 4).

Exotic grasslands

Exotic grasslands cover 835 ha or 12% of the island and are confined entirely to the deep, alkaline calcareous sands on its western side. Earliest grazing would have relied on the persistence of the native grasses, mainly *Poa poiformis* and various inter-tussock herbs. Exotic grasses and clovers that have persisted and dominate in the pasture are *Holcus lanatus, Triticum, Hordeum, Bromus* and *Trifolium* spp. Introduced pasture weeds include *Bellis perennis, Arctotheca calendula, Plantago* spp., *Cerastium* and *Cirsium vulgare.* The native herbs and grasses that have persisted to different degrees within the pasture area include *Ranunculus* sp., *Poa poiformis, Ajuga australis, Isolepis nodosa, Gnaphalium indutum* and *Dichondra repens.*

The exotic grasslands were more extensive in 1968; since then there has been invasion of sand sheets by shrubs.

Grasslands

The native grasslands are mapped as a strip of vegetation on the west coast of Cape Cuvier, although distinct fragments of this native grassland occur on other parts of the east and west coasts. The grassland comprises *Austrostipa stipoides* tussock grassland on the near coastal margin, its width being proportional to the amount of exposure to salt-laden onshore winds (pl.5). Inland from the *Austrostipa* tussock grassland there is *Poa poiformis* tussock grassland. The co-occurring species include *Disphyma crassifolium, Sarcocornia quinqueflora, Distichlis distichophylla* and *Lobelia anceps.* More bare ground is exposed in the *Austrostipa* zone than in the *Poa poiformis* zone where the number of inter-tussock herbs increases. On the eastern shore there are patches and strips of *Ammophila arenaria* and *Spinifex sericeus* in quantities too small to be mapped separately. On the central west coast, mapped as exotic grassland, *Poa poiformis* tussocks form the dominant stratum over most exotic species.

PLATE 4

*Button grass (*Gymnoschoenus sphaerocephalus*) moorland near the central-north of the island.*

PLATE 6

This grassy Eucalyptus viminalis *forest has developed on the alkaline sand sheet northwest of the main airstrip. The forest has developed over 30 years from a sparse open grassy* Eucalyptus viminalis *shrubland.*

PLATE 5

The escarpment slope behind Ainslie Beach. A foredune composed of shell remains is being colonised by Austrostipa stipoides. *The dark lineations on the escarpment are scrub remnants of repeated fires; they are aligned according to the direction of wind-driven fires.*

PLATE 7

A grassy opening in the scrub on an extensive tongue of sands between the homestead and Weber Point. Thirty years previously, this area was Poa *tussock grassland with rare scattered shrubs. The darker shrub on the left is* Acacia longifolia *subsp.* sophorae, *which is rapidly encroaching on the open area.*

Eucalyptus viminalis woodland

This vegetation type occupies only 389 ha or 6% of the island and is a relict of a more widespread former distribution coinciding with the calcareous sand sheets that are well-drained, alkaline and fertile. This vegetation type has suffered the greatest reduction in extent since the occupation of the island by Europeans.

The landward fringes of the sand sheets have some remnant stands of *E. viminalis* woodland (or rarely, forest). A good example was located northwest of the airstrip and is bisected by the Cape Cuvier track (pl. 6). Here the *E. viminalis* low forest canopy is 8 m high and has a 35% cover (see Mueller-Dombois and Ellenberg 1974 for descriptive conventions). Subdominants in the sparse shrub layer at 2 m are *Acacia longifolia* subsp. *sophorae, Leucopogon australis, Banksia marginata, Acacia verticillata* subsp. *verticillata* and *Pimelea linifolia.* A patchy bracken layer at 80 cm high occupies 20% cover. About 70% of the ground layer is grassy comprising *Poa poiformis.* Inter-tussock herbs include *Hydrocotyle* sp, *Swainsona lessertiifolia, Dichondra repens, Ajuga australis, Oxalis perennans, Galium* sp., *Geranium* sp. and *Hibbertia sericea.*

Nodal counts on the *Banksia marginata* indicate a fire approximately 16 years previously (1985). South of the homestead adjacent to the southern track many *E. viminalis* trees still persist — these are up to 60 cm in diameter across the bole. These scattered trees are survivors of frequently burned open grassy woodland. Clearly the fire regime has enabled the persistence of these relicts. Since the changes in management of the island to a less interventionist technique, the process of vegetation thickening has proceeded with abundant regrowth of scrub comprising *Leptospermum laevigatum, Banksia marginata* and *Acacia longifolia* subsp. *sophorae.* Some seedlings of *E. viminalis* are now visible at some sites. *Acacia longifolia* subsp. *sophorae* is a vigorous coloniser that is advancing rapidly from scrub edges into open patches (pl. 7).

Wetlands

The wetlands cover 43 ha or 0.6% of Hunter Island and fall into three categories (fig. 3):

(i) Wetlands on the calcareous sand sheet. These are closer to the west coast of the island, are topographically lower than the other two categories and have more alkaline substrates. They have the highest complement of plant species, including 61% of its combined wetland flora not being shared by the other two groups of wetlands. Some of the species recorded only in the sample as wetland species in this group on Hunter Island are *Juncus articulatus, J. caespiticius, J. holoschoenus, J. bufonius, J. pallidus, Isolepis cernua, Triglochin striatum, Selliera radicans, Carex fascicularis, Hydrocotyle pterocarpa, Crassula helmsii* and *Cardamine heterophylla.*

(ii) The small lagoons perched on the quartzite plateau surface have acid substrates, sandy inorganic floors and are topographically higher than the other two categories of wetlands on the island. Of those we observed, only one appearing typical was sampled. The sampled lagoon had only one plant species (*Drosera pygmaea*) not found in the other two categories of wetlands.

(iii) The lagoons occupying a zone between the other two wetland types are deflation hollows in acid sands with a peaty floor.. This group had six species that were not recorded in the other two wetland types. Some of the species recorded only as wetland species in this group include *Selaginella uliginosa, Juncus procerus, Callitriche stagnalis, Myriophyllum amphibium, Isolepis fluitans* and *Baumea arthrophylla.*

The wetlands are clearly divided into the three groups above on the basis of geomorphology and have distinctive floristic attributes (species richness was compared between the groups by Chi Square and was significant: $P < 0.2$). The wetlands on the alkaline sands and the acid sands both have the same number of plant species, both more than were sampled on the quartzite surface. The proportion of species unique to each group shows a marked decline further from the wetlands on calcareous dunes, which have three times more unshared species than the wetlands on the acid sands which, in turn, have a third more than the lagoons on the quartzite surface.

The lagoons on the quartzite plateau are more floristically related to the precipitation dominant wetlands of south-west Tasmania (Buckney & Tyler 1973) whereas the other two groups are more abundant throughout the northwest and northeast of Tasmania including the larger islands of Bass Strait.

The wetlands have had varying degrees of impacts, mainly from cattle and fire incursion into the edges. Cattle have a big impact on the remaining wetlands on the calcareous sand sheets particularly where grasslands surround them.

Scrub communities

Scrub communities are extensive on the island and cover 2649 ha or 37% of the island.

Any lapse in the traditional fire regime will result in the development of scrub from heathland. It is apparent from historical sources that the proportions of scrub and heath have oscillated. When Robinson walked about the island in the 1830s his commentary implied that the vegetation was very open. This was probably due to the traditional burning practices of the Aboriginal people who used the island. When Dr Grant took up his lease in the 1850s the island was densely scrubby due to the cessation of fire when the

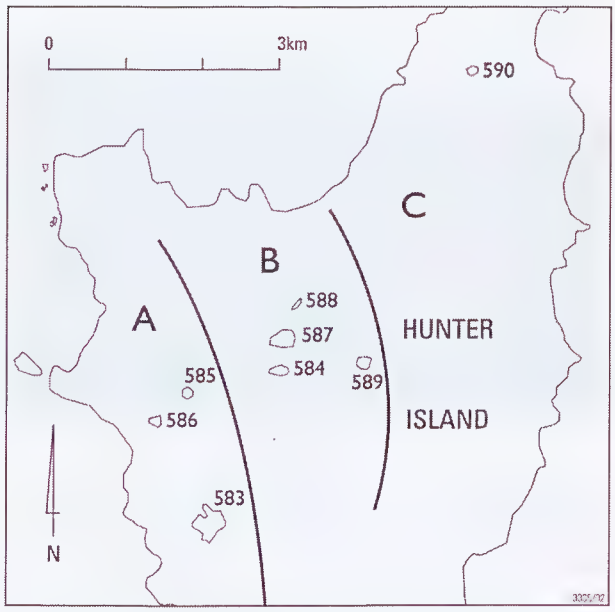

FIG. 3 — Distribution and typology of wetlands sampled by Harwood on Hunter Island. A= Zone of wetlands on calcareous alkaline sand sheet. B= Zone of wetlands on deflation hollows in acid sands. C= Lagoons on quartzite plateau with no organic floor (lowest species diversity). Locations of wetlands are from Kirkpatrick & Harwood (1981).

Aborigines were moved off. Photographs of the island in the 1970s indicate that the proportion of scrub to heath was much lower than it is now.

The scrubs can be conveniently divided into five types: myrtaceous scrubs on acid substrates; myrtaceous-mimosaceous scrubs on calcareous sands; lagoon fringing dense scrubs; *Eucalyptus ovata* riparian scrub; and scrub on Holocene sand dunes on the east coast.

(i) The myrtaceous scrubs on acid sands (pl. 8) include *Eucalyptus nitida*-dominated scrub on the areas that are more fire-protected, such as along the eastern escarpment of the plateau. These scrubs are co-dominated by *Banksia marginata* and *Leptospermum scoparium,* with a diverse mix of species in the understorey. The rocky nature of the ground surface provides a diversity of niches for species to occur, some fire-protected (pls 5, 9) some shady and some very dry. The soils are very skeletal along the escarpment face and at its most convex portion there were individual *Eucalyptus nitida* and *Banksia marginata* that appeared to be dying due to drought.

(ii) The myrtaceous-mimosaceous scrubs on calcareous sands appear to be consistently dominated by *Leptospermum laevigatum, Acacia mucronata* and *Acacia longifolia* subsp. *sophorae. Leucopogon australis* is also common. The understorey comprises a few tussocks of *Poa poiformis* and scattered *Isolepis nodosa.* The soil is typically a deep, well-drained, alkaline, humic loam. Many of these areas that are now dense scrub were open grassy shrubland or woodland 30 years ago.

Open patches usually resulting from wind throw, burning or other disturbances, have an interesting diversity of small herbs and sedges. These include the endangered orchid *Pterostylis cucullata,* the uncommon herb, *Minuartia mediterranea,* and *Gnaphalium indutum, Carex breviculmis, Ajuga australis, Dichondra repens* and *Luzula campestris.*

(iii) The lagoon-fringing scrubs comprise dense thickets

PLATE 8
From the track to the homestead, looking southwest across to Cave Bay. Eucalyptus ovata *scrub lines the creek. The plateau escarpment is in the distant right.*

PLATE 9
The eastern coastal swamp south of Cave Bay, showing the heathy coastal margin shelf and the small pockets of myrtaceous scrub, which have escaped the higher fire frequencies of the coastal shelf.

of *Melaleuca ericifolia* and *M. squarrosa.* Where lagoons are on uncleared land, these scrubs developed markedly in the period between 1968 and 2001. *Melaleuca* scrubs over time encroach on the actual lagoon forming mature swamp forest.

(iv) *Eucalyptus ovata* is usually less than 8 m high and dominates the dense scrub along the few creek-lines draining the plateau surface (pl. 8). At one apparently typical site *E. ovata* 4–5 m high was emergent above a dense layer at 2–3 m of *Pomaderris apetala* subsp. *apetala, Acacia verticillata* subsp. *verticillata, Lepidosperma elatius, Gahnia grandis, Leptospermum scoparium, Melaleuca squarrosa* and *Pimelea drupacea.* Other species in the understorey included *Urtica incisa, Viola hederacea, Gonocarpus teucrioides, Acaena novae-zelandiae, Muehlenbeckia appressa* and *Hydrocotyle* sp.

(v) The scrub on the acid Holocene dunes on the east coast is floristically similar to the myrtaceous scrubs on acid substrates but with the addition of some littoral and near coastal elements.

Mutton-bird rookery vegetation

The principal mutton-bird rookeries occur at both the southern and northern extremities of the island; in each case the vegetation is composed of a patchy mosaic of succulent herbfield dominated by *Carpobrotus rossii* and a succulent shrubland dominated by *Rhagodia candolleana* and *Tetragonia implexicoma* (fig. 2D). Woody shrubs in the rookery areas include *Olearia axillaris* and *Myoporum insulare.* Most of the other species are disturbance-requirers including *Sonchus oleraceus, Cerastium glomeratum, Urtica incisa* and *Cirsium vulgare.* The *Carpobrotus rossii* succulent herbfield at Cape Keraudren is probably the largest in the state and is approached in size only by those patches found on the northwest coast of Prime Seal Island in the Furneaux Group (Harris *et al.* 2001).

Rock (lichen-fields)

Most of the exposed rock occurs around the coast and is especially extensive on the west coast where a wide rocky zone is maintained free of vegetation by the persistently heavy seas. Bluffs and cliffs mark the edge of the plateau escarpment down the eastern side of the island and some rocky bluffs indicate a fossil shoreline inland along parts of the west coast. Close inspection of these rocky areas, except for wave-washed rocks, revealed lichen-fields, the composition of which remains to be explored.

The Flora

As a result of this, and previous studies, 293 vascular plant taxa have been recorded on the island, representing 199 genera in 76 families (see appendix 1). The best-represented families are Asteraceae (n = 27 taxa), Poaceae (n = 26 taxa) and Cyperaceae (n = 21 taxa). Four Tasmanian endemic species were recorded. *Ammobium calyceroides* is an endemic herb confined to the littoral salt spray zone predominantly around Tasmania's west coast and the larger islands of Bass Strait. *Eucalyptus nitida* has closer affinity in form to those on Flinders Island than to other western Tasmanian populations (Rankin 1998). *Phyllota diffusa* is a widespread but uncommon shrub of coastal heathland. *Leptospermum glaucescens* is a common shrub in Tasmanian coastal heathlands.

The species listed on the schedules of the Tasmanian *Threatened Species Protection Act 1995* are *Parietaria debilis, Cotula vulgaris* var. *australasica, Calochilus herbaceous, Cyrtostylis robusta, Ranunculus amphitrichus* and *Pterostylis cucullata.* The first five are listed as rare on Schedule 5; and *Pterostylis cucullata* is listed as endangered on Schedule 3 of the Act. There are some other species of bio-geographical interest and some forms of taxa, which represent extremes in the range of variation. *Pultenaea dentata* is a distinctive form characterised by leaf shape, colour and the presence of a few hairs. It bears a superficial resemblance to *Almaleea subumbellata.*

Olearia glutinosa has its stronghold on King Island with occurrences recorded for Three Hummock Island (Harris & Balmer 1997) and now Hunter Island. There is a specimen in the Tasmanian Herbarium from a collection at the beginning of the track across Robbins Island. Other specimens are occasionally observed in the far northwest of the Tasmanian mainland but no populations have become established. It has been suggested (A. Buchanan, pers. comm.) that seed is blown from King Island and that resulting propagules cannot gain a foothold.

Atriplex billardierei was collected from one site on a sandy beach south of Wallaby Point on the west coast. This species is widespread in Tasmania but is very uncommon.

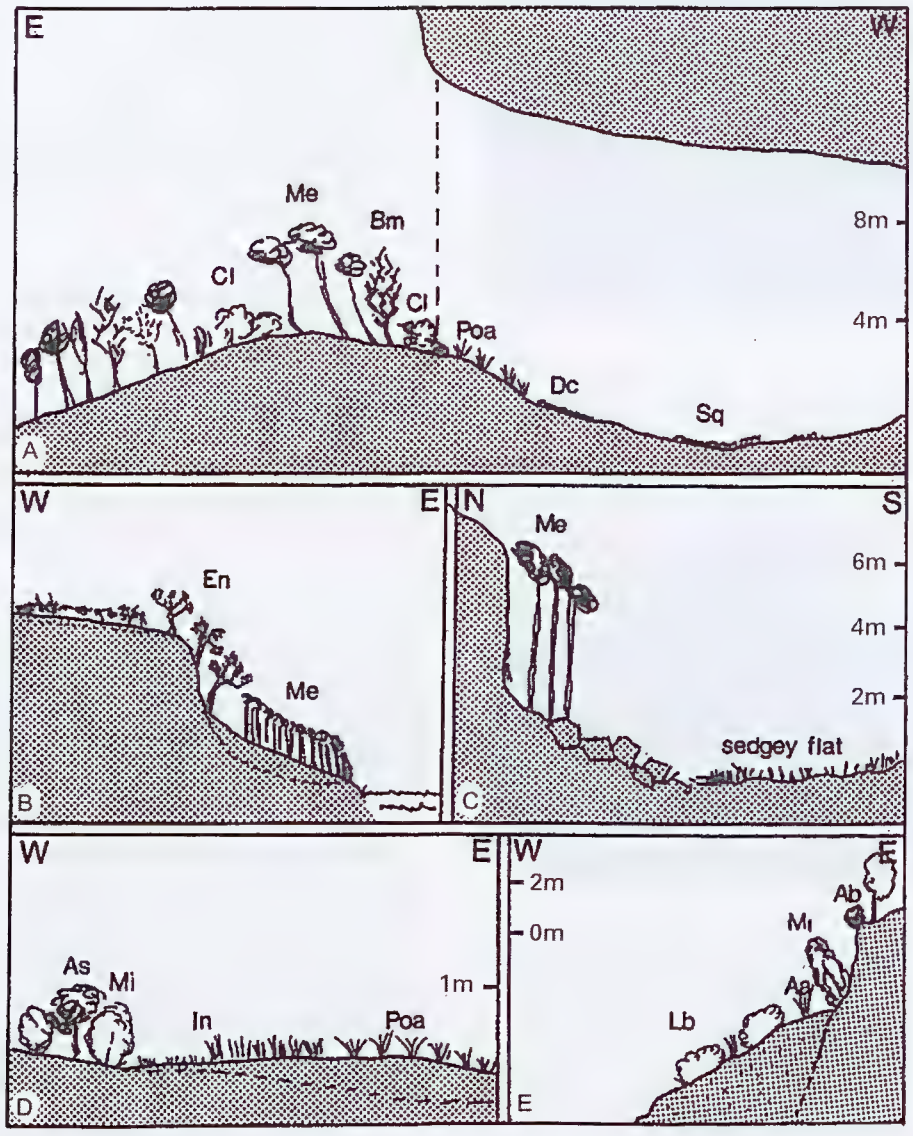

FIG. 4 — Five diagrammatic vegetation profiles from Hunter Island.
(A) The mouth of Cave Bay Cave. The dashed line is the drip line to the west of which the only substantial moisture available is from rain and sea mist blown into the cave. Mats of succulent plants occur in the cave mouth where salt-laden moisture collects.
(B) A stylised section of the east coast north of Cave Bay Cave showing the relative positions of the myrtaceous scrub on the deeper soils of the coastal shelf margin, the Eucalyptus nitida *trees on the rocky escarpment and the heathland on the plateau surface where fire frequency has been highest.*
(C) An inland bluff, probably representing an older sea cliff during a still stand, now has a pediment of angular scree. This profile shows Melaleuca *on the southern side of a bluff where conditions are moist enough to support the lithophytic fern* Asplenium obtusatum.
(D) A boundary between scrub and seabird rookery at the northern end of Hunter Island. Poa poiformis *grassland that characterises the rookery is on deeper sandy soil.*
(E) A steep ramp of sand blown up against a cliff on the western shore is unstable and dominated by two species typical of unstable coastal sands, Leucophyta brownii *and* Ammophila arenaria. *The cliff species are mainly* Alyxia buxifolia *and* Myoporum insulare.
Plant symbols: Aa = Ammophila arenaria, *Ab* = Alyxia buxifolia, *As* = Acacia longifolia *subsp.* sophorae, *Bm* = Banksia marginata, *Cl* = Correa lawrenceana, *Dc* = Disphyma crassifolium, *En* = Eucalyptus nitida, *In* = Isolepis nodosa, *Lb* = Leucophyta brownii, *Me* = Melaleuca ericifolia, *Mi* = Myoporum insulare, *Poa* = Poa poiformis, *Sq* = Sarcocornia quinqueflora.

Minuartia mediterranea is a tiny introduced herb that has been rarely collected in Tasmania. It has probably been overlooked by many botanical collectors and has been collected previously only on calcareous sands on King Island and Three Hummock Island.

Neither *Eucalyptus obliqua* nor *Acacia melanoxylon* have been recorded from the island before. These trees are rare on the island. *Eucalyptus obliqua* occurs commonly in north-west Tasmania and on King Island (Williams & Potts 1996); *Acacia melanoxylon* is similarly abundant on the adjacent mainland and on King Island (Kirkpatrick & Backhouse 1997). Their occurrence in trace proportions may be due to a fire frequency that has disadvantaged them. *Acacia melanoxylon* is known to require between ten and 20 years without intense fire prior to producing seed in the northwest (Sue Jennings, pers. comm.). *Eucalyptus obliqua* is a wet forest species not known to form coppices or large lignotubers, and is therefore more adversely impacted by high fire frequencies than *Eucalyptus nitida.*

Gymnoschoenus sphaerocephalus is a record from the island of biogeographical interest. The species has not been recorded from King Island or other islands in the Fleurieu Group; the Hunter Island occurrence represents a north-western outlier of the species.

The orchid *Pterostylis cucullata* was flowering at the time of our fieldwork. This endangered nationally and state-listed species was represented by a localised population of >100 specimens on the south-facing slope of a calcareous dune northwest of the homestead, in the vicinity where it has previously been reported. Cattle do not have access to the dune in keeping with an earlier recommendation that the *Pterostylis* area be fenced off. No damage by garden snails (*Helix aspersa)* was apparent, as feared by an earlier observer (DPIWE file 50-28-04). A new site for the orchid was found on a dune in scrub at the southern part of the island, at a site burnt about two or three years prior to our survey.

Introduced Species

Sixty-five taxa, comprising 22% of the total Hunter Island flora, are introduced in Tasmania. The most ubiquitous on the calcareous sand sheets outside pasture areas are *Aira caryophyllea, Cerastium* sp. and *Hypochoeris radicata.* The acid soils in heath and scrubs are remarkably weed-free in spite of free-roaming cattle. Lagoons and remnant swamp forests appear also to be weed-free. Weed problems are evident in the coastal swamps and lagoons on the sand sheets where clearing has occurred. These are pasture weeds that have a tolerance for intermittent waterlogging or are annuals that take advantage of suitable areas on the seasonally fluctuating margins of wetlands.

Alien plants have impacted most heavily upon the coastal environment. These plants include ubiquitous species such as *Anagallis arvensis, Sonchus* spp. and *Cirsium vulgare.* The most pernicious weeds are *Euphorbia paralias* and *Ammophila arenaria. A. arenaria* is widespread around the coast on sandy beaches. On Ainslie Beach it forms a continuous band only a few metres wide excluding *Spinifex sericeus.* The only native grass not displaced by *A. arenaria* is *Austrofestuca littoralis. Euphorbia paralias* occurs around the entire coast and appears to have become firmly established on the cobble and broken rocky shores especially in the west. During this survey the central western shore

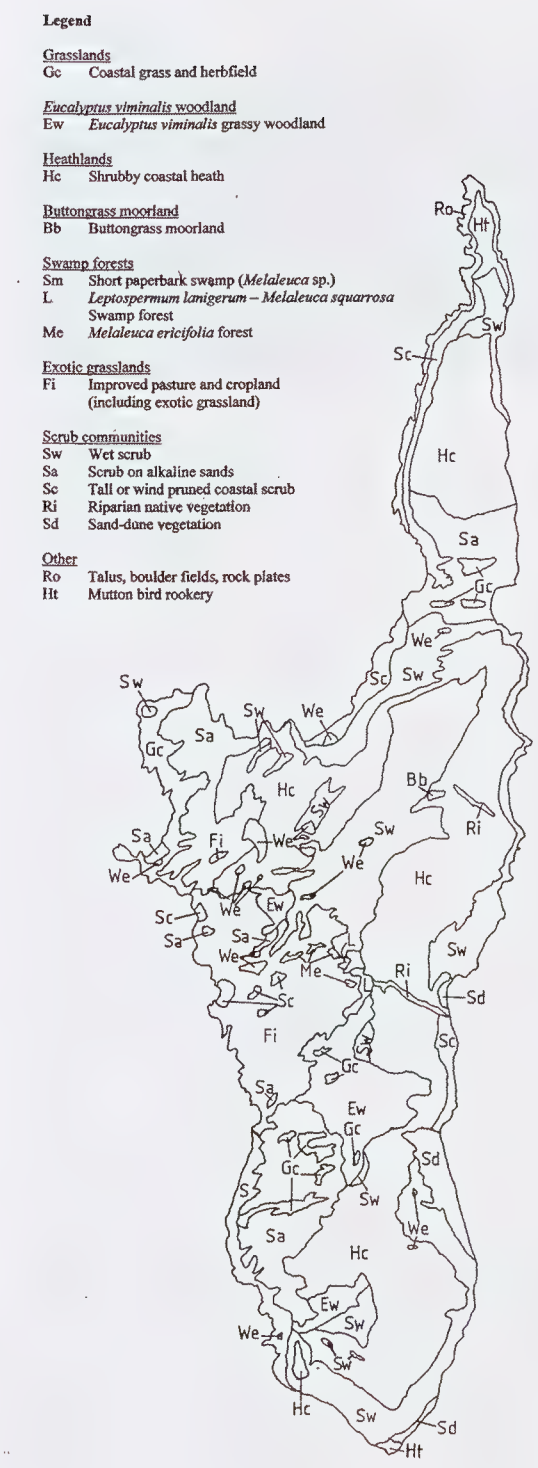

FIG. 5 — Vegetation of Hunter Island.

was examined for *E. paralias* from the northern end of Little Duck Bay (Welcome 1:100 000 map sheet, grid ref. 074103) to the beach at 074069 (Welcome 1:100 000 map sheet). *Euphorbia* colonised the strandline wherever there were embayments with cobble or shingle beaches and sandy beaches. Invasion had commenced in the zone beyond the strandline but was confined to a strip corresponding to the limit of cast sea-wrack. Invasion further inland is localised and confined to small areas of unstable soil. The beach

north of Perigo Point had only occasional specimens of *Euphorbia paralias*. It appears that once the plants become established on pebbly and cobble shores they are less likely to be dislodged by the sea. Cut and fill processes on the sandy beaches may periodically remove whole sections of infestation, causing the fragments and propagules to be washed up on other sections of the coast. Along the east coast, between Cuvier Bay and the end of Ainslie Beach, there are scattered occurrences along the high watermark on sandy sections with the species strongly invading shingle banks above high watermark. Our population estimate for the 4-km section of the west coast we inspected is 8000 and 3000 for the 6-km section of the east coast.

The homestead has not been continuously occupied for many years and garden plants occur there that are confined to the immediate vicinity of the building. These plants demonstrate their ability to survive human neglect. They include *Hydrangea* sp. cult. (Saxifrageae), *Agapanthus orientalis* Leighton (Liliaceae), *Aloe* L. (Liliaceae), *Cordyline australis* (Forst.f.) Endl. (Agavaceae) and Canary Island palm *Phoenix canariensis* Chabaud (Arecaceae). These plants are unlikely to become naturalised on the island.

An 1860 report (cited in Buckby 1989) on the island mentioned the presence of the 'cotton plant' as the reason why sheep do not do well on the island. None of the plants that might fit the description is now known to occur on the island. Indeed, during the Macguire period, large flocks of healthy ewes were run on the island (Tony Macguire, pers. comm., 18 April 2002). *Ptilotus* sp. (Amaranthaceae), sometimes known as 'cotton bush' and *Onopordum acanthium* (Asteraceae), which is sometimes called 'cotton thistle', are not likely to have been the plants referred to in 1860. These are neither toxic nor would they have precluded sheep. It is possible that an infestation occurred of *Gomphocarpus fruiticosa* (Asclepiadaceae), sometimes called 'cotton bush', which is toxic to sheep. This African native is localised in some dry areas of southern Australia, including Flinders Island and Prime Seal Island.

Notes on the Macrofungi

The Tremellales or 'jelly' fungi were found predominantly on dead wood substrates. Occasionally these fungi inhabit living specimens (Fuhrer 1993), which was the case on Hunter Island where *Tremella mesenterica* was found fruiting on *Eucalyptus viminalis*. The species was also associated with dead *Banksia marginata* stems.

The *Panaeolus* and *Poronia* species recorded from Hunter Island are coprophilous fungi that occupy a very specific niche by fruiting on dung substrates. It is interesting that *Poronia* is an obligate coprophile. However, the *Panaeolus* genus exhibits a terrestrial habitat also. The *Poronia* species was found growing on cow manure and is also associated with wombat, kangaroo and rabbit dung (Fuhrer 1993). As previously discussed, the island has been subject to a long history of cattle grazing resulting in an alteration of both non-vascular and vascular flora. Cattle provide an excellent means of dispersing fungal spores, particularly on a small island. However, the ramifications of such dispersal are unknown.

In the modified vegetation, the common field mushroom, *Agaricus campestris*, was located under *Cupressus macrocarpa*. *Lepista nuda* was found in the same habitat. Early European records in Australia indicate that *Lepista nuda* grew primarily with conifers. However, today this species has formed substantial associations with many native species, particularly eucalypts (Fuhrer 1993).

Some fungi located on Hunter Island were tough and leathery, hence more tolerant of drier conditions. Examples of these fungi are listed in appendix 2 under the order Aphyllophorales (see species assigned *). The requirement for water in these species is considerably lower than for the jelly fungi, conferring on them a strong competitive advantage in areas subject to drought. The ability to withstand desiccation has allowed these species to persist in most vegetation communities on the island.

Amanita xanthocephala is a Fungimap species that was recorded only from the relatively dry native grassy woodland.

We frequently observed *Omphalina* and *Hygrocybe* species in the extensive heath on Hunter Island. An *Amanita* sp. was recorded twice on Hunter Island, each time in poorly-drained acidic soil.

Omphalotus nidiformis, or the ghost fungus as it is commonly known, was found on a burnt *Banksia marginata* stump. This fungus, possessing luminescent properties, is often strongly associated with *Eucalyptus* species (Fuhrer 1993). *Daldinia concentrica* was also collected from burnt *B. marginata* stems. This species is commonly located in burnt habitat, with fruiting body production possibly stimulated by fire (Bougher & Syme 1998, Courtecuisse & Duhem 1995).

It is difficult to assess which fungi are introduced. The main reasons are sketchy Australian historical accounts, a poor fossil record and the limitations of incomplete taxonomy for many of the major macrofungal groups. Compounding these difficulties is the likelihood that Australian native species have themselves been introduced to other parts of the world (Australian Biological Resources Study 1996). The identity of vascular plant associates is not a reliable guide to the origin of fungi. However, a working assumption is that those species growing in relatively undisturbed (by humans and feral animals) environments are native. Some examples include *Amanita xanthocephela, Omphalotus nidiformis, Pycnoporus coccineus, Heterotexus peziziformis* and *Tremella mesenterica*. The most notorious introduced species is *Amanita muscaria* (fly agaric), with suspected introductions such as *Lepista nuda* and some of the *Agaricus* species commonly found in association with exotic plant species, such as *Cupressus macrocarpa* and *Pinus radiata*.

We recognise that a more thorough survey would have yielded a larger species list. The absence of ecological literature on Tasmanian macrofungi also impedes a comparison of the species recorded from Hunter Island with those from other regions around the state. However, in establishing a base of mycological information for Hunter Island, we are providing a foundation for further studies.

Chromista

Symptoms consistent with *Phytophthora cinnamomi* infection were observed on the island alongside the track from Ainslie Beach (Homestead Track) and were subsequently confirmed by laboratory isolations from soil samples. The heathy areas over the remainder of the island are very floriferous. Away from the Homestead Track samples taken from dead *Phytophthora*-susceptible plants on the sides of other tracks all returned negative readings. Soil samples taken from soil

at the base of dying *Banksia marginata* shrubs did not test positive for *P. cinnamomi* but indicated an unidentified species of *Phytophthora.*

Schahinger (2001), on the basis of our observations on the apparent limited occurrence of *P. cinnamomi,* has recommended Hunter Island as a management zone (see appendix 3) for the protection of vulnerable heathland communities from *Phytophthora cinnamomi* infection. We do not know the age of the *P. cinnamomi* infection but the existing management regime on the island has most likely delayed its incursion.

GENERAL DISCUSSION

The long history of human use of the island is especially well-documented for the past 200 years. The most significant change to the vegetation since the migration of humans to this area thousands of years ago has probably been the deliberate and accidental introduction of exotic plant species during the relatively short European period. Whereas many of these are both localised and ineffective dispersers or are benign in their effect on native vegetation, some pernicious weeds are present, such as *Lycium ferocissimum,* which is currently very localised and scarce on the island, and *Euphorbia paralias,* which is infesting the shoreline. David Steane noted *Euphorbia paralias* in Tasmania as early as the 1970s at Waterhouse Point; it has since become a major weed of northern Tasmanian coasts and is still spreading. Mutton-bird rookeries are highly prone to weed colonisation.

The most ancient effect of humans on the vegetation of Hunter Island has been the use of fire. It is clear from records at the time of European contact that the Aboriginal population burned the island frequently. There may have been a lull in burning for a few decades between settlement by the sealers and the establishment of a grazing enterprise on the island. Perhaps Robinson's (cited in Plomley 1966) report of 18 June 1830 indicated the commencement of vegetation thickening on the eastern side of the island, where some components of the heath and shrubland will succeed to scrub in the absence of fire: "Crossed over the island to the west side where the sealers have their huts, a distance of about three miles. The travelling across was very bad, through thick forest of tea-tree ...The best part is on the west side and here there is a range of grassy hills". How the fire regime on the island has affected the composition of the flora is uncertain but obligate seeders would tend to become scarce if the frequency was higher than they could cope with. Gunn collected *Gompholobium huegelii* (an obligate seeder in heaths) in 1837 but we did not observe it during our fieldwork.

The decrease in fire frequency over the island from 1968 to the present is apparent from aerial photographs. In the earliest photographs, the texture of the vegetation indicates a uniformly high fire frequency over the entire island. Only tiny pockets of scrub and forest appear to have a lower frequency where they occur in protected sites alongside cliffs (pl. 9). Overall, the impression is of more extensive heathland than presently exists, with the geological and geomorphological features of the island being much more obvious. The tracks and boundaries of particular fires are also clearly visible in aerial photographs of 1968, 1980 and 2000. The dominant directions represent the prevailing wind directions (pl. 10) — their orientations are clustered around two directions, 25° and 70° indicating fires driven

PLATE 10

A fire boundary on the quartzite plateau between heath less than three years old and tall heath/scrub burnt years ago. The boundary is sharp because fires are usually driven by strong winds that cause burn scars to be linear.

by westerly winds. The palaeo-wind directions during the Pleistocene, when the calcareous sand dunes were blown onto the island, appear to be between 50° and 62°. The pattern of some fire scars is influenced by the quartzite structural lineaments that run more or less north–south. Fire scars are often abbreviated or deflected by the quartzite.

Many vegetation boundaries on the island are therefore sharp because of the effect of repeated fires reinforcing topographical features as fire boundaries. The boundaries appear much more pronounced in the 1968 photographs than in the 2000 photographs.

In 1968 almost the complete extent of the calcareous dunes were open and grassy with some areas of open grassy shrubland. Recent aerial photographs from 2001 indicate a shift from this open vegetation type to one of denser cover. On the quartzite, heathland was much more extensive in 1968. However, change in the fire regime has led to the formation of scrub in many areas. The open grassy shrubland has thickened in many places, an example being the development of a substantial *Eucalyptus viminalis* forest with a shrubby component near the limit of a sand sheet north-west of the main airstrip (pl. 6). The most spectacular changes, resulting from a fire regime characterised by longer fire intervals, are visible on the calcareous sands where the post-fire return time for vegetation is likely to be faster due to better fertility and moisture availability compared with the less fertile quartzites. Other notable modifications include the considerable development of scrub behind the first small beach to the west of Cape Cuvier, despite the area having been recently burnt. A comparison between aerial photographs from 1980 and 2001 identified an increase in fringing scrub or forest in many of the island's wetland sites.

The nature of some vegetation boundary transitions and structural profiles is shown in figures 2 and 4.

Palynological evidence supports the change from cold steppe grassland in the Pleistocene to the open shrubland that persisted throughout the Holocene. Human occupation has been attended by a firing pattern about which we know little. It was probably characterised by high frequency. Much of the vegetation is potentially capable of attaining forest stature with a fire-free interval of more than 100–150 years. Small parts of the island have escaped intense

fires over such a period and some pockets of forest occur on the island. Most of the vegetation has probably oscillated between heathland, open shrubland and scrub during the Holocene. The decrease in frequency in the last 30 years has caused an overall thickening of the vegetation. We suggest that this is within the amplitude of changes that have probably existed for many millennia.

The 1968 data indicate that the *Pterostylis cucullata* habitat on a dune northwest of the homestead was unfenced and heavily grazed. However, the situation changed approximately 20 years ago when fencing was constructed to ensure that cattle did not disturb the orchids. Some fences have broken down and cattle occasionally roam into areas where orchids grow.

In October 2001 it was evident that the dieback of *Eucalyptus nitida* and *Banksia marginata* around the tops of cliffs and bluffs, where soil is shallowest, had resulted from previous dry seasons. Some lag time would be expected for wilting point to be reached in sclerophyllous plants. On 4 and 5 June 2002 some further observations could be made on the island. Following an unusually wet spring and summer, drought mortality was striking. On the west coast a series of low rocky rises all stood out because of the dead plants, mainly young *Banksia marginata, Leucopogon* sp., *Pultenaea daphnoides* and *Melaleuca ericifolia.* Additionally, the extent of quartzite outcrops and cliffs on the east coast were now clearly outlined by the pale brown of the dieback. Periods of low rainfall are more likely to be lethal to plants in a place like Hunter Island where strong and persistent maritime winds dump high salt loads.

Floristic comparisons of the quartzite flora with other areas studied in northwest Tasmania indicate that Hunter Island is an impoverished version of the flora at Mt Cameron West Aboriginal Site (Brown 1980) and at Ordnance Point (Cameron 1984). Similar alkaline sand sheets may be rare on the mainland of northwestern Tasmania. However, the extensive dune systems in the northwest are very calcareous due to the spectacularly large volumes of shells. The island has *Eucalyptus viminalis* forest on calcareous sands with high surface pH (8) in contrast with the situation on other Bass Strait and southern Australian coasts. McCoy & Parsons (1974) noted that *Eucalyptus* species that may be widespread on siliceous coastal sands in southern Australia are conspicuously absent from adjacent calcareous coastal sands. Parsons & Specht (1967) found that seedlings of one such eucalypt species showed severe lime chlorosis when grown on calcareous sand. McCoy & Parsons point out that *E. ovata* is a non-calcifuge eucalypt that occurs in dune swales, the habitat in which the species has been noted at Lughrata Dunes on Flinders Island. It would be interesting to examine whether there is intraspecific difference between the Hunter Island population and populations on different substrates elsewhere.

Fungi play a vital role in the ecosystem but our lack of knowledge about them continues to hamper an holistic knowledge of communities. Most mycological research is taxonomically oriented and while this is vital, delays conducting ecological studies may result in lost opportunities for an understanding of our vegetation. We advocate the incorporation of fungi inventories in general vegetation surveys at whatever taxonomic level suits the surveyor's skills. Such inventories should be supported by adequate descriptions, photographs and, where possible, herbaria specimens. Reporting of these surveys in an appropriately cautious manner will provide a basis on which to build knowledge of fungal ecology. A useful approach is suggested by the Fungimap initiative (May 2001) where information from 100 target species is catalogued in a database providing valuable information regarding the frequency and distribution of some Australian fungal flora.

Islands have long been recognised as important to science because they are clearly defined areas where the role of different factors in the workings of the natural system might be more easily comprehended. Where such islands have substantial areas of native vegetation and where the impact of humans has been well-documented, they are especially important. Hunter Island fits these criteria. Further work is required to ensure the human uses of the island are compatible with its long-term nature conservation and cultural heritage values.

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(accepted 9 December 2002)

APPENDIX 1
Higher plant census for Hunter Island

Nomenclature follows Buchanan (2002) except for some orchids, which follow Jones *et al.*1999.
i = introduced in Tasmania.
(i) = formerly extinct on Hunter Island, new introduction.
e = endemic in Tasmania.
ws = wetland survey conducted by Kirkpatrick & Harwood (1981).
tbm = recorded by T. Bruce Muir, National Herbarium of Victoria. Plants found around the central part of the island in November 1973, from an unpublished checklist.

DICOTYLEDONAE
AIZOACEAE
- *Carpobrotus rossii*
- *Disphyma crassifolium*
- *Tetragonia implexicoma*

APIACEAE
- *Apium prostratum*
- *Daucus glochidiatus*
- *Hydrocotyle hirta*
- *H. muscosa* ws
- *H. pterocarpa* ws
- *H. sibthorpioides*
- *Lilaeopsis polyantha* ws
- *Xanthosia dissecta*

APOCYNACEAE
- *Alyxia buxifolia*

ASTERACEAE
- *Actites megalocarpa* tbm
- *Ammobium calyceroides* e
- *Arctotheca calendula* i
- *Apalochlamys spectabilis*
- *Bellis perennis* i
- *Chrysocephalum apiculatum* tbm
- *Cirsium vulgare* i
- *Cotula coronopifolia*
- *C. vulgaris* var. *australasica*
- *Craspedia* sp.
- *Cymbonotus preissianus*
- *Gnaphalium indutum*
- *Hypochoeris glabra* i
- *H. radicata* i
- *Lagenophora* sp.
- *Leontodon taraxacoides* i
- *Leucophyta brownii*
- *Olearia glutinosa*
- *O. lepidophylla*
- *O. ramulosa*
- *Ozothamnus turbinatus*
- *Senecio biserratus*
- *S. pinnatifolius*
- *Sonchus oleraceus* i
- *S. asper* i
- *Pseudognaphalium luteo-album*
- *Vellereophyton dealbatum* i

BRASSICACEAE
- *Cakile maritima* i
- *Cardamine gunnii* ws
- *Lepidium desvauxii*
- *Rorippa nasturtium-aquaticum* i

CALLITRICHACEAE
- *Callitriche stagnalis* i

CAMPANULACEAE
- *Lobelia anceps*
- *Pratia irrigua* ws
- *Wahlenbergia* sp.

CAPRIFOLIACEAE
- *Sambucus gaudichaudiana*

CARYOPHYLLACEAE
- *Cerastium glomeratum* i
- *Colobanthus apetalus* var. *apetalus*
- *Minuartia mediterranea* i
- *Polycarpon tetraphyllum* i
- *Sagina maritima* i
- *Silene gallica* tbm (i)
- *Stellaria media* i

CASUARINACEAE
- *Allocasuarina monilifera*

CHENOPODIACEAE
- *A. billardierei*
- *A. cinerea i*
- *A. hastata*
- *Chenopodium glaucum* i?
- *Rhagodia candolleana* subsp. *candolleana*
- *Sarcocornia quinqueflora*

CONVOLVULACEAE
- *Convolvulus erubescens* tbm
- *Dichondra repens*

CRASSULACEAE
- *Crassula decumbens*
- *C. helmsii* ws
- *C. sieberiana* subsp. *sieberiana*
- *C. sieberiana* subsp. *tetramera*

CUNONIACEAE
- *Bauera rubioides*

DILLENIACEAE
- *Hibbertia prostrata* tbm
- *H. procumbens*
- *H. sericea*

DROSERACEAE
- *Drosera peltata* subsp. *auriculata*
- *D. pygmaea*

EPACRIDACEAE
- *Astroloma humifusum*
- *A. pinifolium*
- *Epacris impressa*
- *E. lanuginosa*
- *Leptecophylla juniperina* subsp. *parvifolia*
- *Leucopogon australis*
- *L. collinus*
- *L. ericoides*
- *Monotoca glauca*
- *Sprengelia incarnata*

EUPHORBIACEAE
- *Amperea xiphoclada*
- *Euphorbia paralias* i
- *E. peplus* i
- *Phyllanthus gunnii*
- *Poranthera microphylla*

FABACEAE
- *Aotus ericoides*

Dillwynia glaberrima
Goodia lotifolia
Kennedia prostrata
Melilotus indicus i
Persoonia juniperina
Phyllanthus gunnii
Phyllota diffusa e
Pultenaea daphnoides var. *obcordata*
P. dentata
Swainsona lessertiifolia
Trifolium repens i
T. subterraneum tbm i

FUMARIACEAE
Fumaria muralis i

GENTIANACEAE
Centaurium erythraea i
Sebaea albidiflora
Sebaea ovata

GERANIACEAE
Erodium sp. i
Geranium potentilloides
G. rotundifolium i
G. solanderi
Pelargonium australe
P. x. *domesticum* i

GOODENIACEAE
Selliera radicans

HALORAGACEAE
Gonocarpus teucrioides
Gonocarpus tetragynus
Myriophyllum amphibium ws

LAMIACEAE
Ajuga australis
Marrubium vulgare i
Mentha diemenica var. *serpyllifolia.*

LAURACEAE
Cassytha glabella
C. pubescens

LEMNACEAE
Lemna minor

LENTIBULARIACEAE
Utricularia dichotoma tbm

MALVACEAE
Malva sylvestris i

MENYATHACEAE
Villarsia reniformis

MIMOSACEAE
Acacia myrtifolia
A. mucronata
A. suaveolens
A. verticillata subsp. *ovoidea*
A. verticillata subsp. *verticillata*
A. longifolia var. *sophorae*

MYOPORACEAE
Myoporum insulare

MYRTACEAE
Calytrix tetragona
Eucalyptus nitida e
E.obliqua
E. ovata
E. viminalis
Leptospermum glaucescens e
L. laevigatum
L. lanigerum
L. scoparium
Melaleuca ericifolia
Melaleuca squamea
Melaleuca squarrosa

OLEACEAE
Ligustrum vulgare i

ONAGRACEAE
Epilobium billardierianum
E. sarmentaceum

OXALIDACEAE
Oxalis perennans

PITTOSPORACEAE
Bursaria spinosa

PLANTAGINACEAE
Plantago coronopus i
P. lanceolata tbm i
P. major i
P. varia tbm i

POLYGALACEAE
Acetosella vulgaris i
Comesperma calymega
C. retusum
C. volubile
Muehlenbeckia adpressa

PORTULACEAE
Calandrinia calyptrata

PRIMULACEAE
Anagallis arvensis i
Samolus repens

PROTEACEAE
Banksia marginata
Persoonia juniperina

RANUNCULACEAE
Ranunculus amphitrichus
R. repens i
R. muricatus

RHAMNACEAE
Pomaderris apetala subsp. *apetala*
P. apetala subsp. *maritima*

ROSACEAE
Acaena pallida
A. novae-zelandiae
Prunus sp. i

RUBIACEAE
Coprosma repens i
Galium australe
Galium murale i
Rosa sp. *i*

RUTACEAE
Boronia anemonifolia
B. citriodora
B. parviflora
Correa alba
C. backhouseana
C. lawrenceana?

SALICACEAE
Salix cinerea i

SCROPHULARIACEAE
Linaria vulgaris i
Limosella australis ws
Mazus pumilio

SOLANACEAE
Lycium ferocissimum i

STACKHOUSIACEAE
Stackhousia spathulata

STYLIDIACEAE
Stylidium graminifolium

THYMELAEACEAE
Pimelea drupacea

Pimelea linifolia
URTICACEAE
Parietaria debilis
Urtica incisa
VIOLACEAE
Viola hederacea

MONOCOTYLEDONAE
ARACEAE
Zantedeschia aethiopica i
CENTROLEPIDACEAE
Centrolepis strigosa
CYPERACEAE
Baumea acuta
B. arthrophylla ws
B. juncea
Carex appressa
C. breviculmis
C. fascicularis ws
Gahnia grandis
G. trifida
Gymnoschoenus sphaerocephalus
Isolepis cernua ws
I. fluitans ws
I. inundata ws
I. nodosa
I. subtilissima
Lepidosperma concavum
L. elatius
L. gladiatum
Schoenus maschalinus
S. nitens ws
S. lepidosperma subsp. *lepidosperma*
Tetraria capillaris
IRIDACEAE
Patersonia fragilis
JUNCACEAE
Juncus articulatus ws
J. caespiticius ws
J. holoschoenus ws
J. kraussii ws
J. pallidus
J. pauciflorus
J. planifolius ws
J. procerus ws
Luzula campestris
JUNCAGINACEAE
Triglochin striatum ws
Triglochin procerum ws
LILIACEAE
Allium sp. i
Dianella revoluta
D. tasmanica
Thelionema caespitosa
ORCHIDACEAE
Burnettia cuneata tbm
Caladenia carnea
C. latifolia
Calochilus herbaceous
C. paludosus tbm
Cyrtostylis reniformis tbm
C. robusta
Microtis parviflora tbm
M. unifolia tbm+
Pterostylis cucullata
P. pedunculata tbm
P. nutans
Pyrorchis nigricans
Thelymitra aristata tbm
T. cyanea
T. ixioides
T. pauciflora
POACEAE
Agrostis avenacea ws
Aira caryophyllea i
Ammophila arenaria i
Anthoxanthum odoratum tbm i
Austrostipa flavescens
Austrostipa stipoides
Briza minor tbm i
Bromus diandrus i
Bromus hordeaceus i
Catapodium marinum i
Dactylis glomerata i
Dichelachne crinita
Distichlis distichophylla
Ehrharta sp.
Holcus lanatus i
Hordeum murinum i
Lolium sp.? i
Notodanthonia semiannularis ws
Parapholis incurva i
Pennisetum clandestinum i
Poa annua i
Poa poiformis var. *poiformis*
Poa sieberiana
Spinifex sericeus
Triticum sp. i
Vulpia megalura i
POTAMOGETONACEAE
Potamogeton australiensis ws
RESTIONACEAE
Apodasmia brownii
Baloskion tetraphyllum ws
Empodisma minus
Eurychorda complanata
Hypolaena fastigiata
Lepyrodia tasmanica
Sporadanthus tasmanicus
XYRIDACEAE
Xyris marginata

GYMNOSPERMAE
CUPRESSACEAE
Cupressus macrocarpa i

PTERIDOPHYTA
ASPLENIACEAE
Asplenium obtusatum
BLECHNACEAE
Blechnum wattsii
DENNSTAEDTIACEAE
Pteridium esculentum
DICKSONIACEAE
Dicksonia antarctica
LINDSAEACEAE
Lindsaea linearis
POLYPODIACEAE
Microsorum pustulatum subsp. *pustulatum*
SCHIZAEACEAE
Schizaea bifida
SELAGINELLACEAE
Selaginella uliginosa

APPENDIX 2
Non-vascular census for Hunter Island

MACROFUNGI

Nomenclature follows *Fungi of Australia* Volume 1A (1996).
F = Fungimap species as targeted by the National Herbarium of Victoria.
W = widely distributed on Hunter Island.
R = observed once only on Hunter Island.
IH = identified twice or more in specific habitats on Hunter Island.

BASIDIOMYCOTA
AGARICALES
- *Agaricus campestris* R
- *Amanita xanthocephala* LC F
- *Amanita* sp. IH
- *Coprinus* sp. (aff. *micaceus*) R
- *Hygrocybe* spp. (1=red; 1=orange-red) IH
- *Lepista nuda* R F
- *Mycena viscidiocruenta* R F
- *Omphalina cromacea* or *ericetorum* W F
- *Omphallotis nidiformis* R F
- *Panaeolus* sp. IH

APHYLLOPHORALES
- *Clavulinopsis* sp. (brilliant orange aff. *miniata*) R
- *Coltricia obtectans* *W
- *Ganoderma* sp. (uncertain identification) *R
- *Polyporus arcularius* *IH
- *Pycnoporus coccineus* *W
- *Stereum ostrea* *IH F
- *Stereum* spp. *W

BOLETALES
- sp. from Boletales R

DACRYMYCETALES
- *Calocera* sp. IH

LYCOPERDALES
- *Lycoperdon* sp. W

TREMELLALES
- *Heterotexus peziziformis* R
- *Tremella mesenterica* IH F

SCLERODERMATALES
- *Scleroderma* sp. IH

ASCOMYCOTA
CLAVICIPITALES
- *Cordyceps gunnii* R

XYLARIALES
- *Poronia erici* or *punctata* R F
- Black Cup fungi W

MYXOMYCOTA
- Small red slime mould (*Fuligo?*) R

LICHENS
All lichen species held at the Royal Botanic Gardens Victoria
CLADIACEAE
- *Cladia aggregata*
- *Cladia retipora*

CLADONIACEAE
- *Cladonia cervicornis* ssp. *verticillata*

PARMELIACEAE
- *Flavoparmelia haysomii*

PHYSCIACEAE
- *Rinodina blastidiata*

TELOSHISTACEAE
- *Caloplaca sublobulata*
- *Teloschistes chrysophthalmus*
- *Teloschistes spinosus*
- *Xanthoria ligulata*

APPENDIX 3
Management recommendations in order of priority

These management recommendations are subject to negotiation with the lessee of the island and are listed here as a basis for discussion.

Fire management
A fire management plan should be prepared for the island, recognising that the current flora and vegetation have survived a very high fire frequency. A plan is required that:
1. Sets appropriate burning frequencies for heath and scrub.
2. Specifies measures for asset protection from fire.
3. Allows for protection from fires of some vegetation types.
4. Allows for research on fire regimes and plant and animal responses.

Feral animals
Confinement of cattle to fenced areas on the central grasslands will assist recovery of some coastal vegetation and wetland margins. The cost of fencing improvements could be offset by the sale of the feral cattle.

Ecosystem threats
The island should be considered as a *Phytophthora cinnamomi* management area and monitored for spread of disease symptoms.

Threatened species
Further surveys and habitat information should be collected for *Pterostylis cucullata* and management actions for the species should be implemented. These actions will act as part of a general recovery plan for the species.

The lessee should be advised of locations of other species of conservation significance and further opportunities taken to define the species extent and condition.

Weeds
Boxthorn (*Lycium ferocissimum*) should be removed from the vicinity of both the homestead and Cape Keraudren as a priority. The species is very invasive, as birds will transport it to other islands and rookeries (Peter 2000).

Sea spurge (*Euphorbia paralias*) should be subject to a concerted eradication/control program on the island as resources allow. These infestations will provide seed for continual dispersal to the north and west coasts of the Tasmanian mainland.

General
The above recommendations should be discussed further with the lessee and considered as part of the lease renewal conditions and a management plan for the Fleurieu Group or for the island.

The Nature Conservation Branch, DPIWE, has identified the island as a suitable site for a field research station. Such a station would be of assistance in carrying out some of the above recommendations.

CENOZOIC PLANT MACROFOSSIL SITES OF TASMANIA

by G. J. Jordan and R. S. Hill

(with one text-figure and one appendix)

JORDAN, G.J. & HILL, R.S., 2002 (31:xii): Cenozoic plant macrofossil sites of Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 136: 127–139. ISSN 0080–4703. School of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania 7001, Australia (GJ*); Centre for Evolution and Biodiversity, South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia; and Department of Environmental Biology, University of Adelaide, South Australia 5005, Australia (RSH). *Author for correspondence.

Tasmania has an outstanding Cenozoic plant fossil record, including several sites of international significance. This paper provides a compendium of macrofossil sites and associated literature. Macrofossils (leaves, fruit, flowers, wood) are known from 59 sites, ranging from Early Eocene to Late Pleistocene in age. Most are Palaeogene to early Neogene, or Pleistocene, with only one Late Neogene deposit. Most late Palaeogene and early Neogene fossiliferous beds are directly overlain by or interbedded between basalt or other volcanic rocks. Others have indirect association with past volcanic activities. Furthermore, most sites are on or near the floors of major valley systems, whether associated with basalt or not. This association with a limited range of environments may cause some biases in the sampling of past regional floras. The ages of these sites may be significant for our understanding of the ages of volcanism in Tasmania, and also suggest areas for further investigation.

Key Words: Palaeogene, Neogene, Pleistocene, geoconservation, Tertiary, palaeoecology.

INTRODUCTION

Most of the literature on the Tasmanian Cenozoic plant fossil record has focused on particular groups of plants, often in the context of other Australian fossils. For example, several papers (most recently Hill & Brodribb 1999) have reviewed the very rich conifer record. *Nothofagus* has also received considerable attention (e.g. Hill 1991a, Hill & Scriven 1997, Jordan & Hill 1999). Tasmanian fossils of Epacridaceae (Jordan & Hill 1996), Proteaceae (Jordan *et al.* 1998) and Cunoniaceae (Barnes *et al.* 2000) have also been reviewed. Only a few reviews have considered whole floras of specific sites. Carpenter *et al.* (1994) and Hill (1995b) presented the most recent specific overviews of Tasmanian plant macrofossil floras, with close attention to several sites of particular significance.

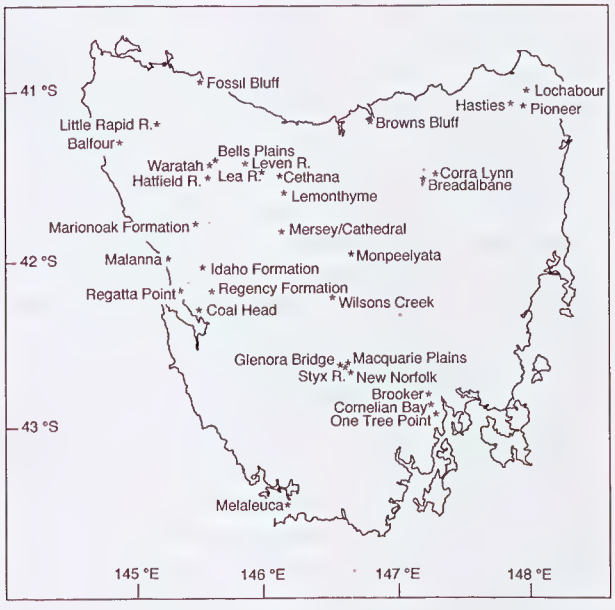

FIG. 1. Locations of selected Tasmanian Cenozoic fossil sites.

This paper reviews the relevant literature and provides a compendium of Tasmanian Cenozoic plant fossil sites. It also considers the relationship of their formation to volcanic activity, and the significance of this for interpreting fossil data. Some of this information was previously presented in Jordan & Hill (1998) but this work is not widely available. Furthermore, the present work includes significant data from drill cores, recent discoveries and analyses.

METHODS

This report combines data from literature and field observations. All sites, except those that have been destroyed, have been visited by the authors in the last five years.

RESULTS

The 59 Cenozoic plant fossil sites in Tasmania that could be precisely located (fig. 1, appendix) can be classified into a few major geographic or temporal categories, as follows.

The Oligo–Miocene Sites of Northwestern Tasmania

Northwestern Tasmania contains many diverse, well-preserved and thoroughly studied Early Oligocene to Miocene assemblages.

Little Rapid River

Road-building for forestry in the 1980s exposed the Little Rapid River fossil locality. The fossiliferous beds have been dated palynostratigraphically as Early Oligocene (Macphail *et al.* 1994). Weathered and presumably undatable basalt overlies the beds, which seem to directly overlie Precambrian rocks. The fossils from this rich and well-studied site have been discussed elsewhere (Hill 1987a, b, 1989, 1990a, b, c, d, 1991a, 1992a, b, 1994a, b, c, 1995a, b, 1997, 2001a, Hill

& Bigwood 1987, Wells 1987, Hill & Carpenter 1989, 1991a, b, Wells & Hill 1989, Read *et al.* 1990, Hill & Pole 1992, Hill *et al.* 1993a, c, Carpenter *et al.* 1994, Macphail *et al.* 1994, Hill & Dettmann 1996, Hill & Scriven 1997, Jordan & Hill 1995, 1999, Jordan *et al.* 1996, Scriven & Hill 1997, Barnes & Hill 1999, Swenson *et al.* 2000). The site is particularly noted for the exceptional diversity of conifers (Hill & Brodribb 1999), and *Nothofagus* (Hill 1987a, 1991a).

Lea River

This well-studied site contains fossils of leaves and reproductive structures (Hill 1990c, Hill 1992a, 2001a, Hill *et al.* 1993a, Carpenter *et al.* 1994, Whang & Hill 1995, Hill & Whang 1997, Jordan *et al.* 1998, Hill & Scriven 1997, Resource Planning and Development Commission 1998, Barnes & Jordan 2000). The fossil-bearing sediment has been dated palynostratigraphically as Early Oligocene (Carpenter *et al.* 1994). It is exposed in two places: a natural river cutting and a nearby gravel pit. At both sites, the sediment appears to lie between basalt flows, although sediment exposed in the river cutting might overlie Ordovician sandstone (see Pemberton & McKibben 1996). Tertiary basalt surrounds the gravel pit exposure, and clearly underlies it. Basalt also occurs opposite the river-cutting beds (Pemberton & McKibben 1996), which are overlain by a soil that may have been derived from *in situ* basalt (John Pemberton pers. comm.).

Cethana

The fossil-bearing siltstone at this reasonably well-studied site has been dated palynostratigraphically as Early Oligocene (Macphail *et al.* 1994). It overlies Late Cambrian–Ordovician sandstone (McClenaghan *et al.* 2001), and is exposed on the side of a steep valley. Tertiary basalt occurs about 2 km to the northeast and 2.5 km to the southeast, but there is no evidence that the deposition of the siltstone was associated with volcanic activity. However, the siltstone is displaced by small scale faults. The siltstone contains compression and impression fossils of an unusually diverse range of leaves, flowers and fruits (Hill 1983a, b, 1984a, 1988a, 1990c, d, 1991a, c, 1992a, b, 1994a, b, c, 1998, 2001a, Carpenter 1988, 1991a, b, 1994, Carpenter & Hill 1988, Hill & Christophel 1988, Hill *et al.* 1988, 1993b, 1995a, b, in press, Hill & Carpenter 1989, 1991a, b, Read *et al.* 1990, Carpenter & Buchanan 1993, Carpenter *et al.* 1994, Carpenter & Jordan 1997, Hill & Scriven 1997, Barnes & Hill 1999). Macrofossils of 56 species have been formally recorded, but many other distinctive forms have not been described because of inadequate preservation (Carpenter 1991b).

Amateur collectors (including school groups) have over-collected this site, and little or no significant material appears to remain *in situ*. Relatively large collections are stored at the University of Tasmania.

Lemonthyme Creek and other drill-core sites

Fine sandstone and siltstone beds occur beneath basalt in Hydro-Electric Commission hole 5825 near Lemonthyme Creek. The beds have been dated palynostratigraphically as Early Oligocene. This site is of considerable interest because the underlying beds have been interpreted as glacial, representing the earliest known Southern Hemisphere Cenozoic glaciation outside Antarctica (Macphail *et al.* 1993). The pollen flora was summarised by Macphail *et al.* (1993), but the siltstone also contains moderately diverse, well-preserved plant macrofossils. Of these, only four species of Proteaceae (Jordan *et al.* 1998), and one of *Callicoma*, from the Cunoniaceae (Barnes & Hill 1999), have been formally documented.

Fossiliferous sediment from a drill-core at Bells Plains has been dated as Oligocene (Hill 1983b), and underlies basalt. This site is of limited interest because of the limited amount of material, with only *Nothofagus tasmanica* (Hill 1983b) and *Athrotaxis rhomboidea* (Hill & Brodribb 1999) formally documented. Other drill cores have been inspected unsuccessfully for fossils. However, sediment overlain by basalt is reasonably common in such cores, and fossiliferous material may have been overlooked. On the other hand, many cores drilled by the Hydro-Electric Commission are now effectively lost, and other core is poorly archived.

Leven River

The Leven River fossiliferous sandstone is exposed on a sharp bend of the river. It is overlain, and possibly underlain, by basalt, and has been dated palynostratigraphically as Early Oligocene (Carpenter & Jordan 1997). It contains fossils of conifer and angiosperms, of which two species have been documented — *Orites excelsoides* (Carpenter & Jordan 1997, Jordan *et al.* 1998, Hill 1998) and *Eucryphia* (Barnes & Jordan 2000), consistent with *E. aberensis* (R. W. Barnes pers. comm.). The preservation is reasonable, but poorer than at sites such as Little Rapid River. The site has potential for further study, although extraction of satisfactory specimens is difficult.

Waratah

Siltstone and occasionally lignite outcrop at the base of Waratah Falls (Seymour 1989). The siltstone is overlain by basalt of the extensive Guildford Plateau. According to Harris (1968, 1973) the palynoflora suggests a Late Oligocene to Early Miocene age. However, most other samples from the Guildford Plateau are of Oligocene age (S.M. Forsyth, pers. comm.). These beds may also be the source of Johnston's (1885a, b, c, 1887) Mt Bischoff fossil flora, from which he described species of *Eucalyptus, Quercus, Ulmus* and others. However, these identifications are unreliable, because they were based on very limited information: Johnston did not use cuticle analysis or make detailed comparisons with extant species. Johnston's original specimens have been lost, and poor line drawings are all that remain of these fossils. The identification of *Eucalyptus* is particularly unfortunate, since it has been subsequently used to suggest a great age for this genus (e.g. Maiden 1922). Similar problems apply to several of Johnston's other Tertiary fossil sites (e.g. Macquarie Harbour and One Tree Point).

Hatfield River and other sediments associated with basalt

Fossiliferous mudstone beds were exposed by road-building on the basalt plateau above the Hatfield River. The mudstone is overlain by basalt, and may have basalt underneath it. It is dated as Early Oligocene (M. K. Macphail, pers. comm.) by palynostratigraphy, and contains well-preserved leaves, fruit and conifer twigs. However, the fossils are quite sparse within the matrix.

Fossil Bluff near Wynyard, northwestern Tasmania, is well-known for its rich shallow-marine fossil fauna (Macphail 1996), as well as a marsupial skeleton. The strata are aged as Early Miocene based on foraminifera, palynostratigraphy and marine faunas (Quilty 1972,

Macphail 1996). Johnston (1888a) reported leaf fossils from this site, although this lens has not been relocated. A moderately diverse spore and pollen assemblage occurs in a lens of terrestrial mudstone near the base of the marine section, although the former may have been transported later from its original site of deposition.

Well-preserved conifer wood (*Athrotaxis* or another Cupressaceae; K. Voltchanskii pers. comm.) was found under basalt in a quarry south of Somerset along the East Cam River road (*Advocate* 13 March 1967). Similar wood was excavated beneath the basalt in the Mersey River, Devonport, in 1999. No sedimentary beds remains exposed at either site and their ages are not known, but may be Oligo-Miocene, based on the peak periods of volcanism in the region (e.g. Sutherland & Wellman 1986). Fossil wood can also be found in strata exposed on the Cradle Mountain Link Road.

Balfour

Gravel exposed in a road cutting in far northwestern Tasmania contains mummified logs, and one lens of compressed organic material, including leaves and reproductive structures. These beds are Oligocene–Early Miocene in age, based on palynostratigraphy (Hill 2001b). They have no known association with volcanic activity. Six species have been recorded from this site. Cupules of five *Nothofagus* species have been recorded, including one new species of the tropical subgenus *Brassospora* (Hill 2001b). The other record is of a fertile leaf fragment of *Lophosoria quadripinnata*, a fern now found only in South and Central America (Hill *et al.* 2001). The lens also contains an undescribed, diverse suite of conifers, including Araucariaceae, Cupressaceae and Podocarpaceae.

The Derwent Graben

Wilsons Creek

Siltstone and fine sandstone at Wilsons Creek in the upper Derwent Valley (Prider 1948) have been dated palynostratigraphically as Latest Eocene–Early Oligocene (Barnes & Jordan 2000). They are overlain by aquagene basalt flows, and also appear to be underlain by basalt. As yet the fossils are poorly studied, but comprise a diverse and abundant assemblage of compressed leaves, conifer stems and reproductive organs. To date, the only published record is of *Eucryphia mucronata*, known only from this site (Barnes & Jordan 2000).

Bushy Park area

Four fossil sites (Macquarie Plains, New Norfolk, Styx River and Glenora Bridge) are associated with volcanic activity that diverted the Derwent River near Bushy Park. Road work at Macquarie Plains exposed a fossil forest of opalised logs more or less in growth position (Hooker 1842, Banks 1955, 1991). It was possibly discovered by Robert Brown in 1804 (Banks 1955, 1991), and was visited by Joseph Dalton Hooker (Hooker 1842) and possibly Charles Darwin (Banks 1991). The logs were up to 1 m diameter and 3 m long, and contained beautifully preserved petrified wood of several species — *Cupressoxylon hookeri* (Arber 1904), *Nothofagus*, *Araucaria*, *Phyllocladus* and *Banksia* (as identified by Mary Calder in a pers. comm. to Max Banks 1964) and other Proteaceae (including *Orites* or *Knightia* according to H. D. Ingle in a pers. comm. to Max Banks 1966). The logs were preserved in tuff associated with the volcanism that produced the local basalt flows. Unfortunately this site has been more or less completely collected and, apart from specimens remaining in the Tasmanian Museum and elsewhere, is now mainly of historical interest.

The New Norfolk site is exposed under volcanic rocks on the Lyell Highway 11 km west of New Norfolk. It has been dated palynostratigraphically as Oligo-Miocene (Hill 1983b). This site is the type locality of *Nothofagus tasmanica* (Hill 1983b). It also contains other undocumented fossils, although the preservation is mostly poor.

The Styx River cuts into organic-rich sandstone beds underneath a road bridge at Glenora, at the southern edge of the basalt ridge that diverted the Derwent River. The sediments are very likely to be of Palaeogene age, based on known dates for local basalt flows and on the presence of conifers and broad-leaved angiosperms in the fossil flora. The sediment may be the lignite near the junction of the Styx and Derwent rivers described by Johnston (1888a).

About 1 km to the east, under the same basalt ridge, lignite dated palynostratigraphically as Early Eocene (Carpenter *et al.* 1994) was excavated on the northern bank of the Styx River (now diverted) at Bushy Park. It contained a well-preserved, conifer-rich flora (Carpenter *et al.* 1994), but only one angiosperm species. No species have been formally described from this interesting site, but specimens at the University of Adelaide are being examined. When visited recently, no *in situ* material was found.

Hobart suburbs

Westward dipping beds exposed in a road cutting on the Brooker Highway near the Box Hill Road overpass contain impressions and some compression fossils of leaves and conifer twigs. The material is believed to be Early Eocene, based on palynostratigraphy (Stephen Forsyth, pers. comm.). Although basalt flows occur nearby these flows are flat lying, and therefore probably younger than the beds. Very little material has been collected, and most is of impression only. The exposure has been graded over and undisturbed material is now buried. Two species of Proteaceae described from the material (Jordan *et al.* 1998) are not known from anywhere else.

The impression fossils in the siltstone under Pipe Clay Bluff on the Derwent River in Hobart have been known for over 120 years (Johnston 1881, Ettingshausen 1888). Their age is almost certainly Palaeogene because of the macroflora, which is dominated by large-leaved angiosperms. However, the preservation (impressions with moderately good preservation of venation details) means that few of the fossils can be identified with any great accuracy.

Two suburban sites containing plant fossils preserved in travertine were exposed by nineteenth-century quarrying. The Geilston Bay site was dated as Late Oligocene, based on an isotopic date of overlying basalt (Tedford & Kemp 1998). The Burnett Street site may be of similar age. Both sites were foci of nineteenth-century palaeobotany in Tasmania (Strzelecki 1845, Darwin 1860, Allport 1866, Johnston 1879b, 1881, 1887, 1888a, Ettingshausen 1888, Banks 1971), although many of the identifications are unreliable (see the notes on the Waratah site). It is not known whether any fossiliferous material remained when the quarries were abandoned, and urban development has made the sites inaccessible. A school playing field covers the Geilston Bay site, and a park covers Burnett Street.

Museum collections from these sites include some of the oldest marsupial fossils in southern Australia (Tedford *et al.* 1975, Tedford & Kemp 1998), and an early record of *Araucaria* (Selling 1950).

Several other sites of Palaeogene age occur in the Derwent Graben, including Johnston's (1888a) sites at One Tree Point, Lindisfarne and Sandy Bay and another site near sea level at Taroona. Although One Tree Point is the type locality for several species (Ettingshausen 1883), the preservation at each of these sites is poor. The beds at One Tree Point are so intensely weathered that no fossils can be collected and the Taroona sediment is also very weathered. No fossil material seems to be accessible at Lindisfarne. Johnston (1888a) recorded fossil leaves from Sandy Bay, in and near the grounds of what is now the University of Tasmania, and others were excavated during building works in the early 1990s. The preservation of this recently located material has not been of sufficient quality to demand further study. A fossil log identified as *Eucalyptus* by H. D. Ingle was found under the Elwick Roundabout (Gill 1962). Its age is unknown.

Northeastern Tasmania

The large area of fluvial gravel near the northeast coast contains several fossil sites exposed by tin mining (Hill 1989). Gravel beds exposed in the abandoned Hasties and Locharbour mines have been dated as Middle–Late Eocene, based on palynostratigraphy (Bigwood 1984, Bigwood & Hill 1985, Bigwood *et al.* 1988, Hill & Christophel 1988). The Hasties beds contains mummified logs, and lenses of finer sediments contain a moderately diverse assemblage of mummified leaves and conifer foliage (Hill & Bigwood 1987, Hill 1990b, c, d, Read *et al.* 1990, Hill & Carpenter 1991a, 1994c, Carpenter *et al.* 1994). The fossil flora, which was summarised by Pole (1992), includes 12 species of conifers and seven of angiosperms. The Locharbour gravels and mudstone lenses (referred to as Loch Aber in the palaeobotanical literature) contain mummified logs, leaves, conifer foliage and reproductive structures. Although this site is moderately well-studied, the good preservation of delicate reproductive structures warrants further investigation. Of the six conifer and two angiosperm species recorded, two are not known from any other site (Hill & Christophel 1988, Hill 1991c, Taylor 1994, Taylor & Hill 1996, Hill & Scriven 1999, Barnes & Jordan 2000).

Mudstone lenses exposed by the Pioneer tin mine contained abundant mummified leaves and reproductive structures. These sediments were dated palynostratigraphically as Late Oligocene/Early Miocene (Hill & Macphail 1983). Volcanic activity may have contributed to the formation of the river system. Balfour (described above) and Pioneer are the only well-preserved lowland floras of this age in Tasmania (Hill 1983b, Scriven & Hill 1997, Hill & Scriven 1997, Jordan & Hill 1999). The site was flooded after mining operations (and hence pumping) ceased, and no more material can be easily obtained.

Other fossils have been recorded immediately below a basalt cap at Pipers River (Marshall *et al.* 1969), and in the Briseis underground mine at Derby (Scott 1937). No more material could be found at the former site, and the latter has been flooded. The Briseis Mine material included well-preserved wood, leaves and fruit. The presence of overlying basalt suggest that both sites are Palaeogene or earliest Neogene.

Launceston Basin

Johnston (1888a) documented many sites in the Launceston Basin that contained plant macrofossils. One such site was Muddy Creek, on the Tamar River. However, the only fossiliferous sediment that has been found recently in the area was at Brown's Bluff at the mouth of Muddy Creek. Fossiliferous sandstones and mudstones form a cliff about 10 m high and extend for at least 100 m along the foreshore of the Tamar. They are of Palaeogene, possibly Palaeocene or Early Eocene age, based on correlation with other sediments in the Launceston Basin. Most specimens are only impressions, but organically preserved fossils can be found in places. These include conifer foliage, angiosperm leaves, Casuarinaceae cones and twigs, and Araucariaceae cone scales. The site warrants further study.

Petrified wood is embedded in breccia cliffs on the northern bank of the North Esk River, south of Corra Lynn. The volcanic activity in the area was probably Palaeogene, and hence the wood would be the same age. Johnston (1874) identified *Banksia* (probably better interpreted as an unidentified member of Proteaceae) and noted that several other taxa were present. Wood fragments remain *in situ*.

Lignite exposed by railway cuttings near Breadalbane, south of Launceston, is probably that mentioned by Johnston (1873, 1874, 1888). The lignite is overlain by sandstone and basalt, and is Palaeogene, based on correlation with other sediments in the Launceston Basin, and on local basalt dates (e.g. an Early Oligocence date on basalt at nearby Cocked Hat Hill; Lin Sutherland, pers. comm.). The fossil flora includes conifer twigs and some angiosperms, but the preservation is poor.

Fossil wood, leaves, twigs and fruit were found in gold diggings in gravel at Brandy Creek, Beaconsfield, in the late nineteenth century (Johnston 1879a, 1880, 1887, 1918, von Mueller 1883, Ettingshausen 1888). *Elaeocarpus* fruits occur in the sediments (Kirchheimer 1935, Rozefelds and Christophel 2000). No material is collectable from this site, which has been highly modified by past mining, although the Queen Victoria Museum (Launceston) and Mineral Resources of Tasmania have some specimens. The location recorded in the appendix is a gold prospect that is the most likely site of the collections.

Johnston (1888) and Milligan (1849) mentioned other sites near Launceston, including Windmill Hill. None could be relocated. Poorly preserved ferruginised leaves occur at Youngtown. Fossil leaves have been recorded from a number of other sites in the area (e.g. Stephensons Bend and Windmill Hill).

Regatta Point and Other Macquarie Harbour Sites

Sediment rocks containing mummified leaves and reproductive structures are exposed in several places around Macquarie Harbour on the west coast of Tasmania (Maiden 1922, Cookson & Eisenack 1967, Baillie & Corbett 1985, Bigwood & Hill 1985, Hill & Bigwood 1987, Tyler & Hill

1988, Hill 1990a, Carpenter *et al.* 1994, Hill & Pole 1994, Hill *et al.* 1993a,b, 1996, 1999). The best studied is about 500 m south of Regatta Point. This has been dated palynostratigraphically as Early Eocene. Much younger (Early Pleistocene) sedimentary rock at the same site is also referred to as Regatta Point (Hill & Macphail 1985). The context usually clarifies which material is being referred to. The Eocene fossils from this site represent a near-coastal flora, including mangroves (Pole & Macphail 1996) and other lowland forest types. They are the most comprehensive Early Eocene fossil assemblage in Tasmania.

A site in a cutting on the abandoned Zeehan–Strahan railway has been known for over 40 years (Banks & Ahmad 1959). In fact it may be the same site as Johnston's (1891) 'Henty lignites'. It contains a variety of seeds and mummified fragments of angiosperm leaves. These have not been studied in any detail, but more intensive study may be rewarding. Their age is unknown, although the large angiosperm leaves suggest Palaeocene or Eocene age. This is supported by the fact that the site is within the Macquarie Harbour Graben.

Sites in Other Regions

Monpeelyata

The fine, fossiliferous sedimentary rock at this well-studied site on the Central Plateau has been dated palynostratigraphically to the Late Oligocene–Early Miocene (Macphail *et al.* 1991). It underlies basalt; local basalts have potassium argon dates ranging from 22.4 to 24.2 million years (Sutherland & Wellman 1986), i.e. earliest Miocene. The sediment was exposed by excavation for a canal. It contains a moderately diverse range of mummified leaves (Hill 1988b, 1990b, c, d, 1991a, 1992b, 1994a, c, 2001a, Hill & Carpenter 1989, 1991a, b, Wells & Hill 1989, Read *et al.* 1990, Britton 1993, Hill *et al.* 1993*b*, Carpenter *et al.* 1994, Jordan & Hill 1994, 1996, 1999, Macphail *et al.* 1994, Hill & Scriven 1997). They form a very early record of a distinctly cold climate flora (Hill & Gibson 1986, Macphail *et al.* 1991, Hill & Scriven 1997).

Richmond

Sandstone in the Coal River Graben near Richmond, southeastern Tasmania, contains a range of impression fossils. The age is probably Palaeocene–Middle Eocene, based on its stratigraphic context, and the presence of fossil leaves of *Nothofagus* (Hill & Carpenter 1999). This site gains its significance from the presence of the only Cenozoic record of *Gingko* in the Southern Hemisphere (Hill & Carpenter 1999). Although there is no sign that the sediment is directly associated with basalt, the Coal River Graben was volcanically active during the Palaeogene.

Buckland

The Eocene Buckland site described by Townrow (1965a, b) contained well-preserved macrofossils of conifers and angiosperms. The fossiliferous mudstone was exposed on the bank of Tea Tree Rivulet. However, the site has not been found again despite careful searching; the exposure was probably destroyed by flood erosion some time in the last 35 years. The fossils are of considerable interest, but little material remains for analysis. The few species recorded at the site include *Athrotaxis*, six other conifers (Townrow 1965a, b) and two species of Proteaceae (Jordan *et al.* 1998).

Dispersed silicified fossils

Silicified fossils of wood, twigs, leaves and fruit of probable Cenozoic age occur in several places in southeastern Tasmania. These are either pieces of wood or leaf and stem fragments embedded in a siliceous matrix. They are usually found spread across the ground, and their origins are not clear. At present they are undatable. A site at Gavins Tier under the Central Plateau includes *Nothofagus* leaves and *Araucaria* stems (see Jordan & Hill 1998 for details). A site near Longs Hill near Richmond contains petrified wood and silicified leaves. Silicified wood has been found near Swansea (Legge 1895), at several sites in the Midlands (Banks 1971, Forsyth 1989), near Burnie, near Bridgewater (Johnston 1888a) and in several places in the Launceston Basin (e.g. Scott circa 1937).

Other sites

Macrofossils have been recorded from a number of other sites, but in each case some aspects of preservation limit their scientific value. Ferruginised fossils can be found at Shark Point, and near Midway Point (southeastern Tasmania) and north of Deloraine (northern Tasmania). No anatomical details are preserved, and dating is problematic. The sites are probably Palaeogene in age, perhaps Palaeocene or Eocene, considering the distinctly broad-leaved floras. Some well-preserved mummified wood can be found at Granville Harbour (Waterhouse 1915, Blisset 1962).

For a large number of sites, there are records of plant macrofossils in museum collections, in notes on old geological maps, or as asides in other publications. None of these sites has been identifed. Details are given in Jordan & Hill (1998).

Late Pliocene and Quaternary Sites of Western Tasmania

Idaho Formation

The Idaho Formation, near Queenstown (western Tasmania), has been dated as latest Pliocene, based on a combination of palynostratigraphy and its geological context (Macphail *et al.* 1995). The only macrofossils known are specimens of *Phyllocladus* wood. However, the primary significance of this flora comes from the pollen and spore flora. It is the only onshore Late Pliocene flora in Tasmania and therefore significant in interpreting palaeoclimates (Colhoun *et al.* 1988, Hill & Jordan 1996, Jordan 1997a).

Regatta Point Early Pleistocene site (RPU)

Quaternary sand and gravel overlying the Early Eocene sediments at Regatta Point are exposed in cuttings. At the base of these sediments, mummified leaves, fruit and stems can be found in angular mudstone clasts embedded in cobbles. The clasts were originally interpreted as having been rafted on ice, but a simpler explanation is that they were derived locally from the collapse of a river bank. The age of most of the fossiliferous mudstone is Early Pleistocene, based on palynostratigraphy (Macphail *et al.* 1993), although one block may be Early–Middle Pleistocene (Jordan *et al.* 1995). The fossil flora is the richest Early Pleistocene flora known from the Southern Hemisphere (e.g. Jordan 1992, 1997b, Macphail *et al.* 1993). It is significant in understanding processes of evolution and extinction in the development of the modern flora (Hill & Macphail 1985, Carpenter *et al.* 1994, Hill & Jordan 1995, 1996, Jordan &

Hill 1991, 1994, 1996, 1999, Jordan 1995a, b, 1997b, 1999, Jordan & Dalton 1995, Jordan *et al.* 1995, 1998, Hill *et al.* 1999, Barnes & Jordan 2000).

Marionoak Formation

Tillite exposed in a west-facing road cutting near a ridgetop between the Huskisson and Marionoak rivers in western Tasmania is underlain by lacustrine mudstone that contains preserved leaves and fruit. Palynostratigraphy and palaeomagnetic data imply that the sediments are Early Pleistocene in age (Macphail *et al.* 1993, Augustinus *et al.* 1997). Only four types of macrofossil have been identified. They, like the fossil pollen (Augustinus *et al.* 1997, Macphail *et al.* 1993), imply a cold climate (Jordan 1997a), and therefore give an indication of the vegetation of near-glacial climates of the Early Pleistocene.

Coal Head

Over 300 tree stumps are preserved in growth position in an area of about 50 m by 25 m on a beach about 1 km north of Coal Head on the eastern shore of Macquarie Harbour (Fowler 1993, Rowell 1995, Rowell *et al.* 2001). The fossils are probably of Late Pleistocene age, although a Middle Pleistocene age is also possible (see Rowell *et al.* 2001 for an explanation). Leaf macrofossils occur in peat between the stumps, and pollen has also been extracted.

City of Melbourne Bay

Jennings (1959) documented wood and pollen fossils from peaty layers at the mouth of Yarra Creek on King Island. One log from the site has a radiocarbon date of 39 000 years BP, although groundwater contamination means that the real age may be considerably greater (D'Costa *et al.* 1993). The peaty sediment at this site contains abundant leaf and fruit fossils, mainly *Phyllocladus* and *Nothofagus*, and is currently being investigated. The more widely known Calcified Forest on the west coast of King Island is in fact calcified root casts of relatively recent origin.

Mersey/Cathedral

Two small outcrops of finely laminated sediment are exposed in a natural cutting on the southern bank of the Mersey River underneath Cathedral Mountain. They are dated as Middle–Late Pleistocene, based on a radiocarbon date of 43 000 years BP and the lack of any extinct species in the pollen flora (Beta–62408; Bresnehan 1993). They contain diverse and well-preserved macrofossils of extant species. All are consistent with sub-alpine to alpine vegetation, and, together with the pollen flora, imply that these fossils come from considerably cooler climates than at present.

Melaleuca, Regency, Rosebery, Langdon River, Pieman Dam, Newton Creek and Dante Rivulet

Several sites containing Middle–Late Pleistocene macrofossils are now no longer collectable for various reasons. The Melaleuca Inlet site in far southwestern Tasmania is possibly the most significant of these. This site is considered to be of Late Pleistocene age, although a Middle Pleistocene age is also possible, based on two radiocarbon dates (38 800 ± 1300, SUA 5038; 43 600 ± 1100, NZA 6745) and palynostratigraphy (Jordan *et al.* 1991, cf. Macphail *et al.* 1993). Note that the latter radiocarbon date has not been previously documented. The site has the youngest record of an extinct plant species in Australia (excluding post-European extinctions). It also contains *Lomatia tasmanica*, now known only as a gigantic clone of great age (Lynch *et al.* 1998). Fossils sedgeland/heath species imply that this kind of vegetation probably grew in the region before humans arrived. The original site was destroyed by mining activities long before it was researched, and no new material can be obtained.

The remaining five sites are near the west coast. They are all now destroyed. The Regency Formation, Langdon River, Pieman Dam (Stringer Creek) and Newton Creek sediments were discovered as a result of excavation or hydro-electric development and the Rosebery site as a result of mine development. All had well-preserved macrofossils. The Regency site is probably of Middle Pleistocene age (see Jordan 1997) although it was originally interpreted as Early Pleistocene (Fitzsimons *et al.* 1990). The other sites are of Middle–Late Pleistocene age (Colhoun 1980, Colhoun & van der Geer 1986, Colhoun *et al.* 1989, 1993). Material from most of these sites still exists in collections. Beds of Last Glacial age on the King River, near Dante Rivulet, contained fossil bolsters of *Donatia novaezelandiae* (Gibson *et al.* 1987). This site was inundated for hydro-electricity.

DISCUSSION

Although Cenozoic plant fossil deposits are widespread in Tasmania (fig. 1), several regions have significant concentrations of sites. Palaeogene and early Neogene sites are concentrated in three types of areas. The first is in the northwest, with associated basalt. The second is in the major block-faulted valleys of the Derwent Graben, the Launceston Basin, around Macquarie Harbour and the Coal River Graben (appendix). The third is the region of fluvial gravels of northeastern Tasmania. Quaternary sites occur across much of western Tasmania, but none is known from the east (fig. 1), probably because low rainfall created unfavourable conditions for the burial and preservation of plant material.

The sites studied intensively over the last 20 years have a narrower geographic range. Most research on Palaeogene and early Neogene fossils in Tasmania has focused on a handful of sites, notably Little Rapid River, Cethana and Lea River in the northwest, Pioneer and Hasties in the northeast, Monpeelyata on the Central Plateau and Regatta Point on the west coast. This is largely due to the excellent preservation at these sites (except possibly at Monpeelyata). However, new finds will no doubt be made at each of these sites.

Fossils have been recorded at a few other sites (Wilsons Creek, Locharbour, Brooker, Macquarie Plains, New Norfolk, Styx River, Buckland, Lemonthyme and Balfour) but only a few in each case. For some sites this reflects limitations of the fossil material. For example, the preservation of fossils at New Norfolk and Brooker is mostly poor, and very limited material is known from Balfour, Buckland and Macquarie Plains. However, the Wilsons Creek fossils are very diverse and well-preserved. Many species — probably dozens or more — remain undescribed from this site. The Styx River, Lemonthyme, Lochabour and perhaps Browns Bluff sites are intermediate between these extremes. In each case the amount of material is small, but each contains fossils warranting description and interpretation. These sites deserve attention to provide broader spatial and temporal coverage of the Palaeogene in Tasmania.

Geological Relationships of the Fossil Sites

Although basalt covers only about 5% of Tasmania's land area (Burrett & Martin 1989), most of the late Palaeogene and early Neogene fossil sites are directly associated with basalt. The soils at many of these sites would probably have contrasted markedly with most other substrates in Tasmania at most times during the Palaeogene. Young lava flows are unusual habitats because they can provide dry, nutrient-poor substrates for plant growth, even in very wet climates. Thus, young lava flows may have provided dry microsites in the otherwise ever-wet conditions believed to have prevailed during the Palaeogene. Weathering of volcanic rocks often leads to the development of highly fertile soils on both weathered basalt and on alluvium derived from volcanic areas. However, large areas of Tasmania are on rock types (quartzites, metamorphics, sandstones and conglomerates) that weather slowly and produce very infertile soils. There is no reason to suggest that this was not also true in the late Palaeogene and Neogene. The contrast between basalt-derived soils and most other Tasmanian soils is well-known (Jackson 1999). Some sites (e.g. Little Rapid River) are overlain by basalt but directly overlie old, nutrient-poor rocks. The nutrient status of the habitats that produced these fossil floras is difficult to determine; the lack of nutrients in the underlying quartzitic rocks may have been compensated by inputs from volcanic ash and from run-off from weathering of nearby basalt.

Finally, volcanic activity initiates disturbances, and several taxa in the Tasmanian fossil record are related to disturbance-dependent living species (e.g. *Fitzroya*, Hill & Whang 1997, *Nothofagus* subgenus *Brassospora*, Hill 1987a, *Nothofagus* subgenus *Nothofagus*, Hill 1994, *Lophosoria*, Hill *et al.* 2001). However, ecological disturbance was probably rare in most of the southwestern half of Tasmania even during periods of high volcanic activity, because of the geological stability and hard rocks. As a result, the source vegetation for those fossil sites associated with basalt probably grew in environments that were quite atypical of the Tasmanian palaeo-environments of the time. The overall fossil record for Tasmania may therefore be biased towards plants with disturbance ecology.

The bias towards disturbance plants would be exacerbated by the well-known biases in the fossil record towards riverine and lacustrine environments. In particular, most Tasmanian fossil sites unassociated with volcanic activity are near the bottoms of major valleys (e.g. Macquarie Harbour). The Tertiary fossil record, therefore, probably provides an unbalanced view of past Tasmanian environments.

A few fossil sites, however, are very significant because they are from contrasting environments and may help overcome these imbalances. Cethana is a critical case. This site appears to have no association with basalt and is not in a major river valley. The fossil flora is distinct, and nutrient-poor soils and possibly dry substrates in some part of the catchment at Cethana have been suggested as explanations of the differences between this flora and other well-known Little Rapid River and Lea River floras of similar age (Carpenter 1991b, Carpenter *et al.* 1994, Carpenter & Jordan 1997, Hill & Scriven 1997). In addition to rainforest taxa, it contains many scleromorphic species, including some 15 species of scleromorphic Proteaceae, none of which has been recorded at any other fossil site (Carpenter & Jordan 1997, Jordan *et al.* 1998). The Middle–Late Eocene floras from Hasties and Lochabour and the Late Oligocene–Early Miocene floras at Pioneer and Balfour are also significant assemblages with no association with basalt.

The ages of the various fossil sites associated with basalt suggests that the period of maximum volcanic activity in northwestern Tasmania was the Early Oligocene. Almost all the fossil sites in this region associated with basalt are of Early Oligocene or indeterminate Oligocene age. In particular, the four sites (Leven River, Waratah, Hatfield and Bells Plains) that are widely distributed on the largest coherent unit of basalt (the Guildford Plateau) are of this age. These include sites both near the base of the basalt making up the plateau, and higher up (Leven River and Hatfield). Thus, this plateau of about 900 km^2 may have been formed in a single, relatively short period of volcanic activity.

Future Prospects

The widespread occurrence of fossil sites, their small sizes and their idiosyncratic locations together suggest that new sites will be found. Almost all the sites were discovered serendipitously. A few were noted through geological mapping, many were drawn to our attention by word of mouth but few, if any, by systematic search for such fossil sites. Road-building and other excavations, mainly associated with hydro-electric development, mining and forestry, have exposed many sites. As landscape alteration continues, the exposure of new, significant fossil sites seems inevitable.

The most valuable material (e.g. at sites such as Little Rapid River, Lea River, Cethana and Regatta Point) has organic preservation of such quality that anatomical details of the cuticle are preserved. Such material often weathers quickly and degrades. For example, the surface material in the Early Pleistocene sediments at Regatta Point is heavily weathered, and the best material has been excavated. More extreme still is the degradation of R. M. Johnston's nineteenth-century sites, few of which now contain well-preserved fossils. As a result, exposures containing high-quality plant fossils could be considered temporary, although good preservation may persist in deeply buried parts. There are some exceptions. For example, well-preserved fossils can be easily found at the Lea River site because erosion of this natural river cutting is continually creating fresh exposures. The same is true at Wilsons Creek.

Silicified fossils by contrast weather very slowly, but are of little significance in the Cenozoic of Tasmania. Most sites of Cenozoic silicified plant fossils have been over-collected (e.g. Macquarie Plains) or contain only fragments transported from unknown sources. They are extremely difficult to date.

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APPENDIX
Cenozoic plant-fossil sites with known locations

Site	Age	Basalt*	Grid references†
Northwest Region			
Little Rapid River	Early Oligocene	overlying	3545 54400
Lea River	Early Oligocene	overlying (?underlying)	4157 54044, 4153 54046
Cethana	Early Oligocene	none	4280 54075
Lemonthyme	Early Oligocene	overlying	4291 53923
Leven River	Early Oligocene	overlying (?underlying)	4024 54098
Hatfield River	Early Oligocene	overlying (?underlying)	3796 53993
Cradle Mountain Link Rd	Early Oligocene	overlying (?underlying)	3945 53986
Waratah	Oligocene	overlying	?3765 54116
Bells Plains	Oligocene	overlying	3809 54215
Balfour	Oligo–Early Miocene	none	3239 54274
Fossil Bluff	Early Miocene	overlying	3932 54625
East Cam River	? Oligo–Miocene	overlying	4024 54502
Devonport	? Oligo–Miocene	overlying	4465 54410
Derwent Graben			
Wilsons Creek	Latest Eocene	overlying (?underlying)	4554 53146
New Norfolk	Oligo–Miocene	overlying	4962 52686
Brooker	Early Eocene	?overlying	5201 52618
One Tree Point	Palaeogene	overlying	5291 52485
Macquarie Plains	Palaeogene	overlying and overlying	4930 52721
Glenora Bridge	Palaeogene	overlying	4909 52724
Cornelian Bay	Tertiary	?indirect	5264 52548
Taroona	Early Tertiary	overlying (?underlying)	5290 52458
Burnett Street	?Palaeogene	none	5254 52516
Geilston Bay	Oligocene	overlying and underlying	5282 52569
Styx River	Early Eocene	?overlying	4918 52717
Lindisfarne Bay	?Palaeogene	overlying and underlying	5290 52552
Sandy Bay	?Palaeogene	?indirect	5270 52500
Elwick roundabout	?	?	5235 52578
Northeast Region			
Hasties	Middle Eocene	none	5745 54593
Pioneer	Early Miocene	? indirect	5779 54526
Lochabour	Middle Eocene	none	5850 54676
Pipers River	Cenozoic	overlying	5060 54480
Derby Deep leads	Cenozoic	overlying (?underlying)	5671 54448
Launceston Basin			
Brown's Bluff	Early Eocene	none	5030 54225
Breadalbane	Palaeogene	overlying (?underlying)	5180 54019
Corra Lynn	?Palaeogene	none (but in breccia)	5181 54072
Youngtown	?Early Eocene	none	5123 54073
Beaconsfield deep leads	?Palaeogene	?	4838 54403
Macquarie Harbour Region			
Regatta Point	mostly Early Eocene	none	3618 53303, 3625 53302, 3571 53474 etc
Mallanna	Palaeogene	none	3571 53474

APPENDIX cont.

Site	Age	Basalt*	Grid references†
Coal River Graben			
Richmond	Palaeogene	indirect	5367 52692
Shark Point	Palaeogene	?overlying	5409 52620
Longs Hill	?Palaeogene	?	5332 52703
Other sites			
Monpeelyata	Oligo–Miocene	overlying and underlying	4722 53453
Gavins Tier	?Palaeogene	?	5280 53374
Granville Harbour	Early Eocene	none	3452 53674
Buckland	? Early Eocene	none	5638 52810
Latest Pliocene/Pleistocene sites			
Idaho Formation	Latest Pliocene	none	3838 53421
Marionoak Formation	Early Pleistocene	none	3759 53847
Regatta Point	Early Pleistocene	none	3618 53303
Coal Head	Late Pleistocene	none	3705 53145
Mersey/Cathedral	Late Pleistocene	none	4256 53635
City of Melbourne Bay	Late Pleistocene	none	2535 55672
Newton Creek	Late Pleistocene	none	3816 53596
Regency Formation	Middle Pleistocene	none	3873 53307
Langdon River	Middle Pleistocene	none	3784 53525
Melaleuca Inlet	Late Pleistocene	none	4322 51914
Rosebery	Middle Pleistocene	none	3788 53744
Dante Rivulet	Late Pleistocene	none	3894 53452
Stringer Creek	Middle Pleistocene	none	3448 53787

* Associated Cenozoic basalt, and its position relative to the fossiliferous beds
† All grid references are based on Australian Geodetic Datum 1966 (to nearest 100 m).

RADIOCARBON DATING OF MUMIYO FROM THE VESTFOLD HILLS, EAST ANTARCTICA

by Kevin Kiernan, Anne McConnell, Eric Colhoun and Ewan Lawson

(with one table and one text-figure)

KIERNAN, K., MCCONNELL, A., COLHOUN, E. & LAWSON, E., 2002 (31:xii): Radiocarbon dating of mumiyo from the Vestfold Hills, East Antarctica. *Papers and Proceedings of the Royal Society of Tasmania* 136: 141–144. ISSN 0080–4703. School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia (KK*, AMc); Department of Geography and Environmental Science, University of Newcastle,Callaghan, NSW 2308, Australia (EC); Australian Nuclear Science and Technology Organisation, PMB 1, Menai, NSW 2234, Australia (EL). *Author for correspondence.

Accelerator mass spectrometer (AMS) radiocarbon dating of mumiyo deposited by snow petrels at nesting sites in the Vestfold Hills indicates the colonies were established after 4800 yr BP (uncorrected for marine reservoir effect). Sites on the highest hills were probably established first, but colonisation took place long after initial deglaciation, which was well advanced by 12.5k yr BP. The reason for late colonisation is not known. Perhaps older sites exist, but current evidence suggests the main colonisation occurred after the mid-Holocene re-advance of the Sørsdal Glacier. $\delta^{13}C$ values indicate a diet of krill.

Key Words: Antarctica, Vestfold Hills, mumiyo, AMS radiocarbon dating, snow petrels.

INTRODUCTION

In Antarctica, mumiyo, a waxy accumulation of proventricular oil ejected by nesting snow petrels (*Pagodroma nivea*) (Warham *et al.* 1976), has been radiocarbon-dated to estimate the timing of the initial deglaciation of fringe areas of the continent and establishment of the snow petrel populations. Conventional radiocarbon dating of mumiyo from the Untersee Oasis of central Dronning Maud Land (71°S, 13°E) recorded discontinuous petrel occupation since 34 kyr BP (Hiller *et al.* 1988); two samples from the Robertsoskollen nunatak group, northern Ahlmannryggen, Dronning Maud Land (~71°S, 3°E), suggested that occupation began in about 7 kyr BP (Ryan *et al.* 1992) and in the Bunger Hills, Wilkes Land (66°10'S, 101°45'E), occupation began before 10 kyr BP (Verkulich & Hiller 1994).

This paper reports accelerator mass spectrometer (AMS) radiocarbon dates from snow petrel nesting sites in the Vestfold Hills, East Antarctica (fig. 1). The Vestfold Hills oasis covers an area of about 413 km^2 and has a maximum altitude of 158 m. Four marine inlets, locally termed 'fjords', penetrate the hills deeply. The East Antarctic Ice Sheet bounds the hills on the east and the Sørsdal Glacier bounds them on the south. The extent to which the hills were submerged by the ice sheet and glacier during the Vestfold Glaciation — considered to represent the last glacial maximum — is debated (Adamson & Pickard 1986, Fitzsimons 1991, Gore 1997). The age of deglaciation is minimally constrained by cosmogenic isotope exposure-age dating of subglacial erratics within 1–2 km of the ice sheet's margin that indicated almost complete deglaciation by 12.5 ± 1.6 kyr BP (Fabel *et al.* 1997). Fitzsimons & Domack (1993) showed that the southern hills had been transgressed by the sea by 9 kyr BP, and that re-advance of the Sørsdal Glacier eroded the marine sediments between 9 and 0.7 kyr BP. Adamson & Pickard (1986) suggested that this re-advance occurred between 3 and 1.5 kyr BP.

METHOD

Mumiyo deposits were obtained by Kevin Kiernan and Anne McConnell during the 1996–97 austral summer with logistical support provided by the Australian Antarctic Division. Field sampling aimed at obtaining the oldest mumiyo deposits. Only basal samples were taken from most accumulations, though at a few sites with thick deposits, additional samples were taken at different levels in the sequence. Care was taken not to disturb nesting birds. The altitudes of the sample sites were recorded (table 1). Few sites had deposits more than 10–20 mm thick. The basal 2 mm were carefully scraped from the deposit to avoid clastic impurities that might contain old carbon. The samples were wrapped in aluminium foil and plastic bags, and refrigerated for transport to Lucas Heights for analysis. The $\delta^{13}C$ content, per cent modern carbon and conventional radiocarbon age were determined by Ewan Lawson using the ANTARES accelerator mass spectrometer facility at the Australian Nuclear Science and Technology Organisation laboratories at Lucas Heights, NSW, Australia.

RESULTS

The radiocarbon ages obtained from the basal mumiyo samples, uncorrected for marine reservoir effect, range from 4800 ± 60 yr BP (OZD 192) to 500 ± 140 yr BP (OZD 190) (table 1). Radiocarbon measurements of modern marine samples from Antarctica have given ages of 830–1460 yr BP, with a mean of 1180 yr BP (Stuiver *et al.* 1986, Hiller *et al.* 1988, Gordon & Harkness 1992, Ryan *et al.* 1992). Modern samples of marine algae and shells from the Vestfold Hills have given ages of 950–1310 yr BP (Adamson & Pickard 1983, 1986). Using a value of 1300 yr BP for the marine reservoir effect would make the sample from Boulder Hill (OZD 185) close to modern and the sample from Inner Long Peninsula of 500 ± 140 (OZD 190) yet to be deposited. As the appropriate correction factor is uncertain, none has been applied here because to do so would introduce further uncertainty in the age estimates. The earliest dates indicate

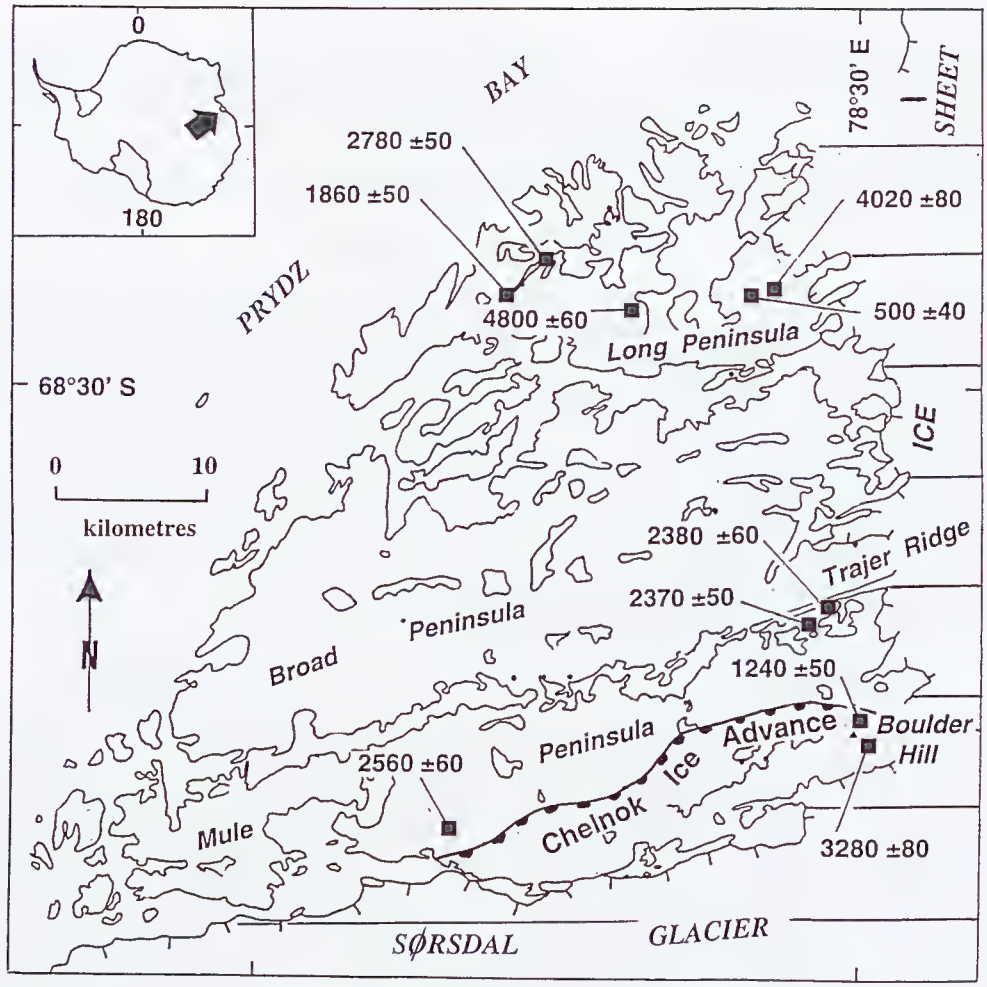

FIG. 1 — Location of dated mumiyo samples from the Vestfold Hills, East Antarctica.

TABLE 1
Location and age of mumiyo samples from the Vestfold Hills

Site	Sample no.	Altitude (metres)	Mumiyo thickness (mm)	δ13C (‰)	^{14}C age (years, uncorrected)
Boulder Hill	OZD185	110	150	–28.62	1240±50
Boulder Hill	OZD186	80	140	–29.00 *	3280±80
Trajer Ridge	OZD187	80	100	–29.80	2380±60
Trajer Ridge	OZD188	70	140	–30.18	2370±50
Inner Long Peninsula	OZD189	140	<10	–29.94	4020±80
Inner Long Peninsula	OZD190	70	180	–30.95	500±140
Outer Long Peninsula	OZD191	40	<50	–28.25	1860±50
Outer Long Peninsula	OZD192	75	<50	–29.58	4800±60
Outer Long Peninsula	OZD193	30	<50	–30.22	2780±50
Poseidon Plain	OZD194	20	70	–29.99	2560±60

* assumed value

that the Vestfold Hills were probably colonised by snow petrels only as recently as 4800 (uncorrected) years ago and at least 8000 years after the initial deglaciation.

Since only 10 samples have been dated, the age of colonisation may be underestimated. However, as six of the samples were collected within 2–3 km of the ice sheet, the colonisation was probably widespread by 3500 yr BP. There is little pattern in the age distribution of the petrel sites, except that those on high points may be slightly older than those in adjacent low areas, although the reverse occurs at Boulder Hill.

Rates of mumiyo accumulation range from 0.002 mm/yr (OZD 189) to 0.360 mm/yr (OZD 190). The thickest accumulation of mumiyo recorded during this survey was deposited in only 500 years. The rate of accumulation at a site appears to be independent of the basal age of the sample. This suggests that occupation of nesting sites may have been discontinuous in the long term. However, accumulation of 180 mm in only 500 years at Vestfold Hills, giving an average of 0.360 mm/yr, is a much faster rate than any recorded at Bunger Hills (Verkulich & Hiller 1994) or at Robertsoskollen nunataks (Ryan *et al.* 1992).

DISCUSSION

The establishment of snow petrel colonies at Vestfold Hills appears to be much later than at other coastal nunataks and oases of East Antarctica. To what extent the ages of 34 kyr BP in the Untersee Oasis (Hiller *et al.* 1988) and the >10 kyr BP of the Bunger Hills (Verkulich & Hiller 1994) reflect absence of ice in these areas during the last glacial maximum is difficult to ascertain. At Bunger Hills, intensive colonisation occurred between 8 and 6 kyr BP and after 2 kyr BP. Only the latter phase appears to be temporally related to the late Holocene establishment of snow petrels at Vestfold Hills.

There is considerable evidence in coastal East Antarctica of advancing outlet glaciers during the mid-Holocene. From studies of the Mertz–Ninnis Trough, Dumont d'Urville Trough and Amery Depression, Domack *et al.* (1991), showed that grounding-line advance of outlet glaciers led to deposition of terrigenous sediment on the continental shelf between 7 and 4 kyr BP. Marine biogenic sediments overlie these deposits. They also showed that in Prydz Bay, to the west of Vestfold Hills, open marine conditions existed between 10.7 and 7.3 kyr BP.

A widespread advance of the East Antarctic Ice Sheet margin on the Wilkes Coast during the mid-late Holocene was attributed by Goodwin (1996, 1998) to ice thickening in central-East Antarctica due to 50% higher precipitation in the Holocene than during the last glacial maximum and to slow ice sheet flow response rates. This increased ice volumes in the coastal zone between 4 and 2.5k yr BP. Modelling suggests that a temperature increase of 5°C is required to cause the ice sheet to recede (Huybrechts & Oerlemans 1990). Ice-core data suggest that temperatures were 0.5°C warmer around 4k yr BP. Cooling occurred from 2 kyr to 1 kyr BP when there was brief warming before the Little Ice Age. Temperatures during the Little Ice Age were about 0.5°C colder than present (Ciaias *et al.* 1994, Mayewski *et al.* 1995, Morgan *et al.* 1997).

Adamson & Pickard (1986), and Fitzsimons & Domack (1993) showed that the Sørsdal outlet glacier had advanced again recently in the southern part of the Vestfold Hills. Adamson & Pickard (1986) suggested that this Chelnok Advance occurred between 3 and 1.5 kyr BP. As Boulder Hill lies within this ice limit, the older date for mumiyo of 3280 ± 80 yr BP (uncorrected) is broadly consistent with their estimate. Fitzsimons & Domack (1993) showed that slabs of sheared ice formed the cores of the sediment masses associated with moraine of the Chelnok ice advance, and that the ice limit may have been attained as recently as 710 yr BP (corrected age).

Collectively, this evidence supports the hypothesis that re-advance of outlet glaciers in the peripheral zone of East Antarctica during the mid-late Holocene was associated with climatic conditions less favourable for snow petrels than in the subsequent three or four millenia. Snow petrels apparently colonised the Vestfold Hills during the milder conditions following the last advance of outlet glaciers in coastal East Antarctica. The inferred climatic evidence suggests that average temperatures did not change by more than about 1°C during this period.

The late Holocene colonisation by snow petrels at Vestfold Hills bears comparison with evidence of abandoned penguin rookeries in East Antarctica. Adélie penguins were abundant on the Victoria Land coast between 4 and 3 kyr BP, probably due to abundant open water and reduced snow cover. Many colonies were abandoned ~3 kyr BP, but were re-established about 1.4–0.8 kyr BP (Baroni & Orombelli 1994). Similarly, abandoned rookeries in the Windmill Islands were occupied from 4–3 kyr BP (Goodwin 1998). The open water conditions that facilitated the establishment of penguin rookeries are likely to have been associated with higher air and sea-surface temperatures that promoted greater coastal precipitation (Goodwin 1998). Sea-surface temperatures interpreted from stable oxygen isotope ratios of calcareous marine fauna and diatom transfer functions suggest sea-surface temperatures were 0.5–1.0°C warmer than now at 4 kyr BP (Pichon *et al.* 1992, Goodwin 1998). However, unlike Adélie penguins, snow petrels are not reliant on near-shore food sources. Hence, reduced open water inshore is less likely to affect the viability of colonies than is greater snowfall during warm periods, notwithstanding enhanced summer melt.

The $\delta^{13}C$ values of mumiyo offer some insight into the likely foods available to snow petrels. Ryan *et al.* (1992) suggested that $\delta^{13}C$ values for tissues from animals that feed on Antarctic fish are likely to be –24.5‰ or –26 to –27‰ if the diet consists of Antarctic krill. The $\delta^{13}C$ values reported for mumiyo range from –29 to –31.1‰. Mean values determined from snow petrel body tissue are –28‰ (Ryan *et al* 1992, Verkulich & Hiller 1994). The values obtained from Vestfold Hills mumiyo range from –28.25‰ to –30.95‰, which is closer to the figures suggesting a diet of krill than of fish.

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FIRE HISTORY OF THE NORTHERN PART OF THE TASMANIAN WILDERNESS WORLD HERITAGE AREA AND ITS ASSOCIATED REGIONS

by K. A. Johnson and J. B. Marsden-Smedley

(with one table and two text-figures)

JOHNSON, K. A. & MARSDEN-SMEDLEY, J. B., 2002 (31:xii): Fire history of the northern part of the Tasmanian Wilderness World Heritage Area and its associated regions. *Papers and Proceedings of the Royal Society of Tasmania* 136: 145–152. ISSN 0080–4703. Fire Management Section, Parks and Wildlife Service, GPO Box 44 Hobart, Tas 7001, Australia.

Fire history (from the 1820s to 2000) in the northern quarter of the Tasmanian Wilderness World Heritage Area and its associated regions is discussed in this paper. This area includes Cradle Mountain–Lake St Clair National Park, Granite Tor Conservation Area, Walls of Jerusalem National Park and the Central Plateau Conservation Area west of Great Lake. In common with fire history in southwest Tasmania, there have been major changes in fire regimes during the last 180 years, with major fires in the 1890s (most probably in 1896–97 or 1897–98 or both) and the 1930s (most probably in 1933–34). However, in contrast to southwest Tasmania, there were major fires until the early 1960s: in the early 1950s in the Cradle Mountain–Lake St Clair National Park and Granite Tor Conservation Area, and in 1960–61 in the Walls of Jerusalem National Park and the Central Plateau Conservation Area. Between the 1930s and 1960s over 40% of the study area or about 129 000 ha was burnt. About half of the study area's fire-sensitive vegetation (i.e., alpine, subalpine heath, subalpine rainforest, rainforest and native conifer) was burnt in these fires. The last of these fires — the 1960–61 Central Plateau fire — was the biggest and most destructive fire in the World Heritage Area since the 1930s. Less than 3% of the study area was burnt between 1970 and 2000.

On Wednesday, November 16, had the camp moved to the foot of Barn Bluff; and on Sunday, the 20th, taking three of the party with me, I went to the summit of that mountain, hoping to obtain a good view of the country to the westward. By aneroid I made the summit of Barn Bluff 5045 feet above sea, but failed to get a good view of the country I wanted to see, owing to the dense volume of smoke arising from numerous bush fires enveloping the country in almost every direction.

E. G. Innes, District Surveyor, 1896

Key words: fire history, western Tasmania, World Heritage Area.

INTRODUCTION

There is considerable anecdotal evidence of major changes in the fire regime of Tasmania's Wilderness World Heritage Area (WHA) since the removal of the indigenous Tasmanians in the early nineteenth century. The changes are reflected in the extensive areas of highly fire-sensitive alpine, rainforest and native conifer plant communities that have been severely degraded by fire in the past 180 years (Brown 1988, Peterson 1990, Robertson & Duncan 1991, Corbett unpubl. 1995). These plant communities are very slow to recover after fire (in the order of 500 to 1000 years). They are also considered to be of world heritage significance (PWS 1999). Their destruction is therefore of great concern and the changes in fire regime have major implications for management and ecological processes of the WHA.

The fire history of southwest Tasmania over the past 180 years has been reported (Marsden-Smedley 1998a, b). That study area encompassed Southwest and Franklin–Gordon Wild Rivers National Parks and those parts of the Southwest Conservation Area that are on Cape Sorell or adjacent to the King River and Macquarie Harbour. This paper continues the study of fire history to include Cradle Mountain–Lake St Clair National Park, Walls of Jerusalem National Park, Granite Tor Conservation Area and the part of the Central Plateau Conservation Area that is in the WHA (fig. 1).

In common with the fire history study of southwest Tasmania, this paper aims to describe fires since the early 1800s. The outcomes of this work are descriptions of the major fire events before the 1930s, maps of all known fires from the 1930s to the 1990s, and estimates of the area of different vegetation types burnt. For additional information on this project see Johnson & Marsden-Smedley (2001).

METHODS

Aims

Using published papers, field work, aerial photographs and pre-existing fire history maps, this paper aims to build up a picture of the region's fire history before 2000. With the exception of the Walls of Jerusalem National Park and Central Plateau Conservation Area west of Great Lake (fig. 1), fires before 1930 have been described, with fires after 1930 being mapped. On the Central Plateau, fires before 1960–61 have been described and fires after this time have been mapped. The map of the 1960–61 fires and some later fires was obtained from Corbett (1995). Information on fires that occurred in the 1980s and 1990s was obtained from the Fire Management Section of the Parks and Wildlife Service.

Information from published papers, aerial photographs and field surveys was used to generate fire-history maps at 1: 25 000 scale for the northern part of the WHA. Estimates of the area of different vegetation types burnt at different times have been made by laying the fire-history maps over the fire-attributes vegetation map published in the WHA Tactical Fire Management Plan (PWS 2000).

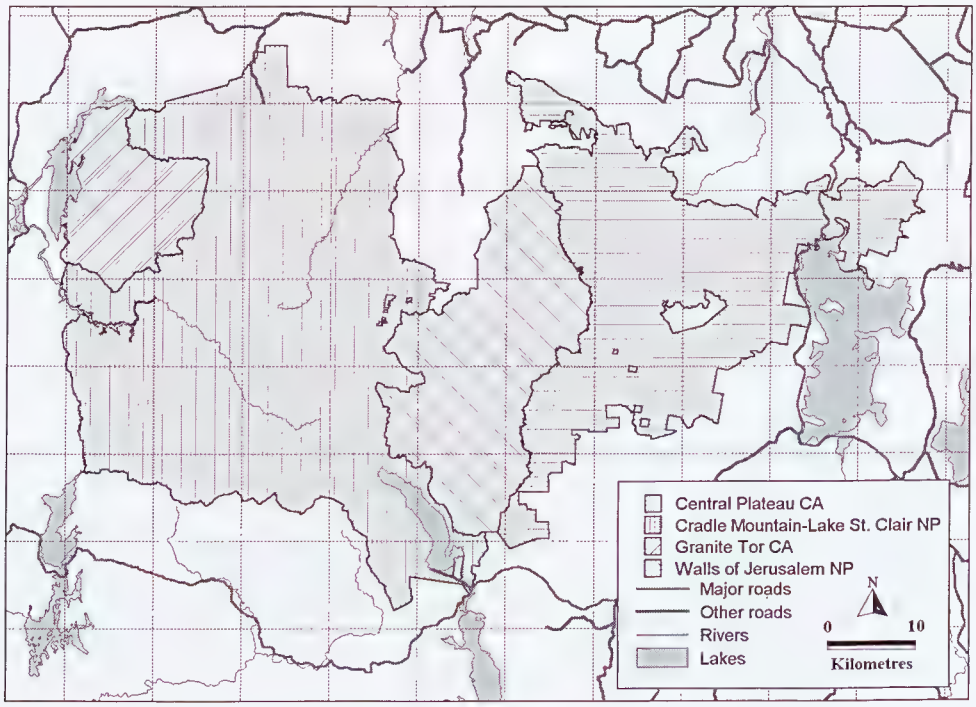

FIG. 1 — Area examined in this project.

Published Papers

The following sources provided particularly useful information on historical fires: *Tasmanian House of Assembly Journal, Legislative Council Journal, The Mercury, The Tasmanian Mail, The Weekly Courier, Explorers of Western Tasmania* (Binks 1980) and *A View to Cradle* (Haygarth 1998).

Although these references give an indication of where and when fires occurred, they generally contain minimal information on the size, extent and severity of the fire. While providing an overview of fires, they tend to concentrate on official expeditions, often undertaken by government employees, and to ignore exploration and burning by private parties. As a result, these sources almost certainly greatly underestimate the occurrence of fire in the study area. They have been used as spot references in the recording of fires from the 1820s to 1930.

Aerial Photograph Interpretation

Aerial photographs (held at the Department of Primary Industries, Water and Environment) taken of the project area between 1947 and 1982 were examined for fire boundaries. Corbett (1995) produced a map of fire boundaries for the Central Plateau WHA, spanning the period 1961 to 1993. As a result, only photographs pre-dating 1961 were examined for the present study.

The interpretation of fire boundaries on aerial photographs was made challenging by the highly variable quality and scale of the photographs. In particular, there were large differences in contrast between different aerial photograph projects, between runs within projects and even between adjacent photographs.

Long time intervals between photograph runs also created problems in interpretating fire scars; for example, no aerial photographs of the study area taken in the 1960s were located. As a result, there are gaps of 20 to 26 years between aerial photograph runs over the whole project area. This complicated the interpretation of photographs from the 1970s in particular, as fire scars could disappear (regenerate) or be hidden by subsequent fire events during this long interval. There is also an absence of early photographs pre-dating mapping done by Corbett (1995) covering the Central Plateau. Almost half of the Central Plateau Conservation Area assessed in this study had little or no coverage from before the late 1960s to the mid-1970s.

Growth rates of different vegetation types after fire also created difficulties for mapping. Shrubby alpine vegetation holds fire scars for much longer than grassy or buttongrass moorland vegetation, which made the placement of fire boundaries across different vegetation types difficult. The mapping of frequently burnt areas and patchy fires (particularly in country with a large amount of rock scree, such as the Central Plateau) was found to be a much more difficult task than mapping large or high intensity fire events. Much of the area where patchy burning has traditionally taken place coincides with the areas described above as having insufficient aerial photograph coverage for mapping purposes (i.e., Central Plateau).

Field Data

Vegetation ages were collected from 57 sites within the study area. Primarily, ages were estimated from tea-tree and paper-bark ring counts (*Leptospermum nitidum, L. lanigerum, L. scoparium, L. rupestre* and *Melaleuca squamea*). With the exception of *L. rupestre*, these species have been widely used in studies of site age because of their reliable annual rings and widespread distributions (Jarman *et al.* 1988a, b, Marsden-Smedley 1998a, b, Marsden-Smedley *et al.* 1999).

A dissecting microscope was used to make ring counts from the lower surface of cross-sections. Cross-sections were cut from as close to ground level as practical, dried and polished with up to 1200 grade sandpaper (Marsden-Smedley *et al.* 1999). The number of stems sampled at any one site ranged from two to 11. Time and practicality constraints of remote area field trips (up to 10 days' duration) resulted in a small number of samples from some sites.

Node counts from *Banksia marginata* were used to assist in determining site age (Bell 1983, Jarman *et al.* 1988a, Marsden-Smedley *et al.* 1999). Nodes tended to be obscure and difficult to count on older banksias. As a result, banksias were used to gain an indication of minimum site age and, where possible, were used in conjunction with ring counts. Site ages were also obtained for 16 sites from Jarman *et al.* (1988a).

RESULTS

The results are divided into two time periods: before the 1930s, and from the 1930s to the 1990s. The first of these periods relies on historical literature, while the second incorporates mapping from this project and contemporary literature.

Fires before the 1930s

On the night of the 24th December, 1840, a fearful storm of lightning occurred here. It was for a long time unaccompanied by either rain or thunder; and the flashes, which succeeded each other at very short intervals, were singularly vivid; showing plainly at each recurrence, the rugged outline of the wild landscape around us. As we were watching the storm from our rocky fortress, we witnessed a most unusual occurrence. The recent hot weather had parched the herbage of the plain to perfect dryness, and a flash, more tremendous than any that had preceded, suddenly set it in a blaze. We were beginning to be a little alarmed for the security of our position in the tenement we occupied, which was surrounded by dry herbage, mixed largely with dry brushwood, but shortly afterwards relieved from our apprehensions by a copious shower of rain extinguishing the fire. (J. E. Calder in 1840 at Christmas Rock on Lightning Plain, which is south of the study area (Calder 1849)).

The fire was now raging with fearful violence, the whole sky being blue with smoke, which made everything lurid and unnatural ... The country was black for miles; not a speck of green could be seen, except the myrtle forest which clothed the side of Mount Gell. (W. A. Tully near the upper Franklin River in 1859. The fire was started by a spark from his camp fire.)

The occurrence of natural and accidental fires, such as those witnessed by Calder and Tully, cannot begin to compare with the widespread and deliberate use of fire during the latter part of the nineteenth century. Explorers and prospectors used fire as a tool to cut tracks into unmapped territory and to expose the substrate. The west coast mineral boom of the 1880s created a demand for access to the mining areas of Zeehan and Mount Lyell and also for tracks to take prospectors and geologists into new regions.

Near Mount Kate, in the north of the study area, Fossey's (1827) expedition observed open country (Cradle Valley and Hounslow Heath) with stands of snow gums, pencil pines and fagus (Binks 1980). Gould's 1859 to 1860 expedition also noted relatively clear spurs and open country between Barn Bluff and Lake Windermere and noted that open moors existed south of Lake Will (Binks 1980). It is likely that fairly regular burning occurred over at least some of the buttongrass plains within the study area. Legge (1887) describes the Vale of the Cuvier as '*park-like*' and *studded here and there with clumps of young gums ... We found it much overgrown, as it has not been burnt out for four or five years, and the walking was consequently very heavy ... On our return* [from Lake Hermione] *we found the buttongrass in the valley, and though it was drizzling at the time a huge fire sprung up at night and burnt all the following day, so that the next pedestrians who ascend Olympus will have better walking than we had.*

In November 1896, large bushfires were observed by Innes (1897) while cutting and marking a track from Mole Creek to Rosebery (see quote at the beginning of this paper). In the tradition of the times, Innes' party fired the countryside to assist in their movement through it ... *Aylett and Innes carried out their instructions well. Leaving my camp upon Granite Tor on February 2, they pushed through to Mount Black, firing the country anywhere there was a chance to burn it.*

Marsden-Smedley (1998a) suggests that a large proportion of southwest Tasmania burned during the 1890s. This included much of the country between the West Coast Range, Hartz Mountains and the Southern Ranges. Further north, the latter part of the nineteenth century was also a time of fire.

The bushfires of 1897–98 started in December 1897; the last day of 1897 came to be called 'Black Friday'. These fires burned for most of the rest of that summer, devastating large areas. A column in the *Illustrated Tasmanian Mail* (8 January 1898) summed up the fires on the west coast (reported from Zeehan and all around, including the Northeast Dundas tramway, Mount Read, Mount Hamilton, Queenstown and Mount Lyell) under the heading 'Unprecedentedly extensive and disastrous fires'. It went on:

Very heavy bush fires have been raging with even increased vigour in this district for several days past, and more serious damage is reported at Zeehan and all around ... The recent devastating bush fires on the West Coast have not been utterly devoid of redeeming points. They have cleared away miles of almost impenetrable bush and scrub, so that the prospector may now carry out his work with a tithe of the toil and trouble previously inseparable from hunting out lodes.

The *Illustrated Tasmanian Mail* (8 January 1898) reported that fires were also lit around Lake St Clair on either 26 or 27 December 1897. Photographs in the Archives Office of Tasmania show the extent of these fires. Photographs from 1901 show that fire had already taken its toll on the area around Mount Pelion West and Pinestone Valley (aged in this project to the mid- to late 1890s). However, this landscape was no stranger to fire. Dead trees are prevalent around Lake St Clair and Mount Arrowsmith in photographs from 1863 (Morton Allport collection *'First Views'*). The effects of fires near Mt Arrowsmith were also described by Walker (1887). Site ageing around Cradle Valley suggests that a major fire event occurred in the late 1890s (probably 1897–98).

While surveying and cutting a track from Lake Selina to Lake St Clair in 1900, Ewart was forced to avoid the Coal Hill area (head of Cuvier Valley) becaue of fire (Ewart 1901):

On starting from Eldon Bluff to reach Lake St. Clair, everything proceeded satisfactorily until Pine Hill [Junction Hill] *was surmounted, about seven miles out, when I noticed there was a dense smoke in the vicinity of Coal Hill, which lay in the direction I wished to take. Thinking bush fires were raging, I decided to make for the overland route from Hobart, taking a course south from Gould's Pyramid.*

Kirkpatrick & Balmer (1991) suggested that three major fires occurred in the late 1800s and/or early 1900s in the area around Cradle Mountain and Pencil Pine. Photographs from the 1920s show the area between Barn Bluff and Cradle Mountain and the slopes of Hansons Peak as burnt, while ageing of banksias indicates fires probably occurred near Lake Dove in the 1890s and Lake Rodway in both the 1890s and 1930s. There are signs of much older fires in the landscape, including one that may have burnt from the northwest over Hounslow Heath (Kirkpatrick & Balmer 1991). The lowland grasslands and sedgelands around Cradle and Pencil Pine have been frequently burnt since European occupation (Kirkpatrick & Balmer 1991).

Jetson (1993) stated that by the mid-1820s wild cattle had moved to the Central Plateau, by the 1830s the seasonal movement of stock from lower to higher altitudes was common practice, and by the 1850s firing of grasslands and buttongrass plains had become established practice. On the Central Plateau, it is difficult to separate the effects of fire and domestic grazing. However, according to Cullen (1995) the Central Plateau has suffered serious sheet erosion and degradation as a result of 150 to 170 years of grazing and burning (see also Banks 1972).

In the 1800s and early 1900s in western Tasmania the extensive use of fire in exploration and prospecting was a widely accepted and generally socially acceptable practice. Regardless of this, the use of fire was such that it led Counsel (1898) to make the following comments:

In new and expanding agricultural settlements there is a considerable demolition of timber beyond that which is actually necessary in the clearing of land, by reason of the extra prevalence of spreading fires; but one of the main points to which I desire to direct especial attention in this Report is the enormous consumption of valuable timber which is in the process of being destroyed in the Mining Districts, particularly on the West Coast ... there is the wholesale and reckless destruction of the forest growth, young and old, by bush fires in all directions during many months of the year, whilst there is no constituted authority at the present time to prevent the lighting of such fires on the unoccupied Crown Lands, except where it has been specially reserved.

Perrin (1898) also made comments relating to the condition of Tasmanian forests stating that it:

... is infinitely worse to-day than it was at date of my Report in 1886-7. Another decade of waste, of private monopoly, of fierce bush fires, of neglect by the Government to check the damage to public property, must ultimately result in disaster to the industries and thousands of people dependent upon the timber resources of the Colony ... The bush fires about Lyell, Zeehan, the Pieman, and Lake Dora, &c. have already destroyed timber which it will cost shareholders in the mines many thousands of pounds more than they would otherwise have had to pay to replace by drawing from other localities.

Perrin goes as far as to suggest that a stringent Fire Act be drafted without delay to prevent what he saw as the excessive and haphazard use of fire:

In order to clear prospecting claims it is quite an ordinary custom for the prospector to set fire to the timber and let the flames spread at will over as much of the surrounding countryside as they can reach ... This is ignorantly regarded as a creditable and serviceable exploit in 'clearing the country,' no consideration being given to the fact that timber destroyed in this haphazard fashion will be wanted later on, and can only be replaced at great cost ... But in addition to the miner, the careless use of fire by the splitters and wood-cutters must also be dealt with, and a comprehensive measure should therefore be framed at once to prevent the recurrence of those disastrous fires which have already wrought such havoc.

From the 1820s to the 1920s the use of fire in the study area was widespread and deliberate. As will be seen below, this pattern continued for the next few decades.

Fires from the 1930s to 1990s

The early 1930s was a time of extensive fires in south-western and western Tasmania. According to Marsden-Smedley (1998a) the extent of fire in the 1930s was second only to its extent in the 1890s. This trend of extensive fires appears to have extended to the north to include the area covered by this study. During the 1930s, there were several major fires. Kirkpatrick (1984) suggests two severe fire events (probably in 1933–34): one that burnt most of Pyramid Mountain and another that burned Rocky Hill. Fires were also observed near the Eldons by Warren (1936):

... bushfires down Jane River way, smoke near Lake Vera and fires burning fiercely in the West. Westward the sky black and flame coloured. Near the Eldons a huge column of smoke rises steadily up above the clouds, a long straight column, opening at the top like a gigantic mushroom.

The major fire observed near the Eldons may have left the large fire scar mapped in the vicinity of Walled Mountain and Macs Mountain (fig. 2). It extends north at least as far as James Creek, east to the DuCane Range, up the valley of the Narcissus River to Falling Mountain, and west to near the Bluff River. Photographs from 1936 in Haygarth (1998) show burnt forest surrounding DuCane Hut, although it is not clear how extensive this fire was. Part of Mount Oakleigh was mapped as burnt on the 1947 aerial photographs and the adjacent February Plains show a history of fire from this time right through to the 1980s. The Cuvier Valley also has a history of fire, as seen on the aerial photographs and by stands of dead pencil pines (Johnson & Marsden-Smedley 2001).

Further east on the Central Plateau, fire events observed on the 1947 aerial photographs were difficult to map. Although there is a distinct fire boundary in the vicinity of Chapter Lake, Lake Bill, Lake Louisa, Lake Adelaide and to the west and north of Lake Myrtle, a complete boundary could not be given to this fire. As a result it is not shown in figure 2. Another boundary, potentially from much the same time, was located in the area between Lake St Clair and Travellers Rest Lake, with evidence of fire extending in a patchy nature to the east. An important detail recorded by Jetson (1993) in a personal interview with shepherd Jacky Reid states that the 1933–34 fires extended to Lake Naomi and Gowanbrae.

Another major fire event occurred between 1947 and 1953 (most probably in the early 1950s) in the vicinity of

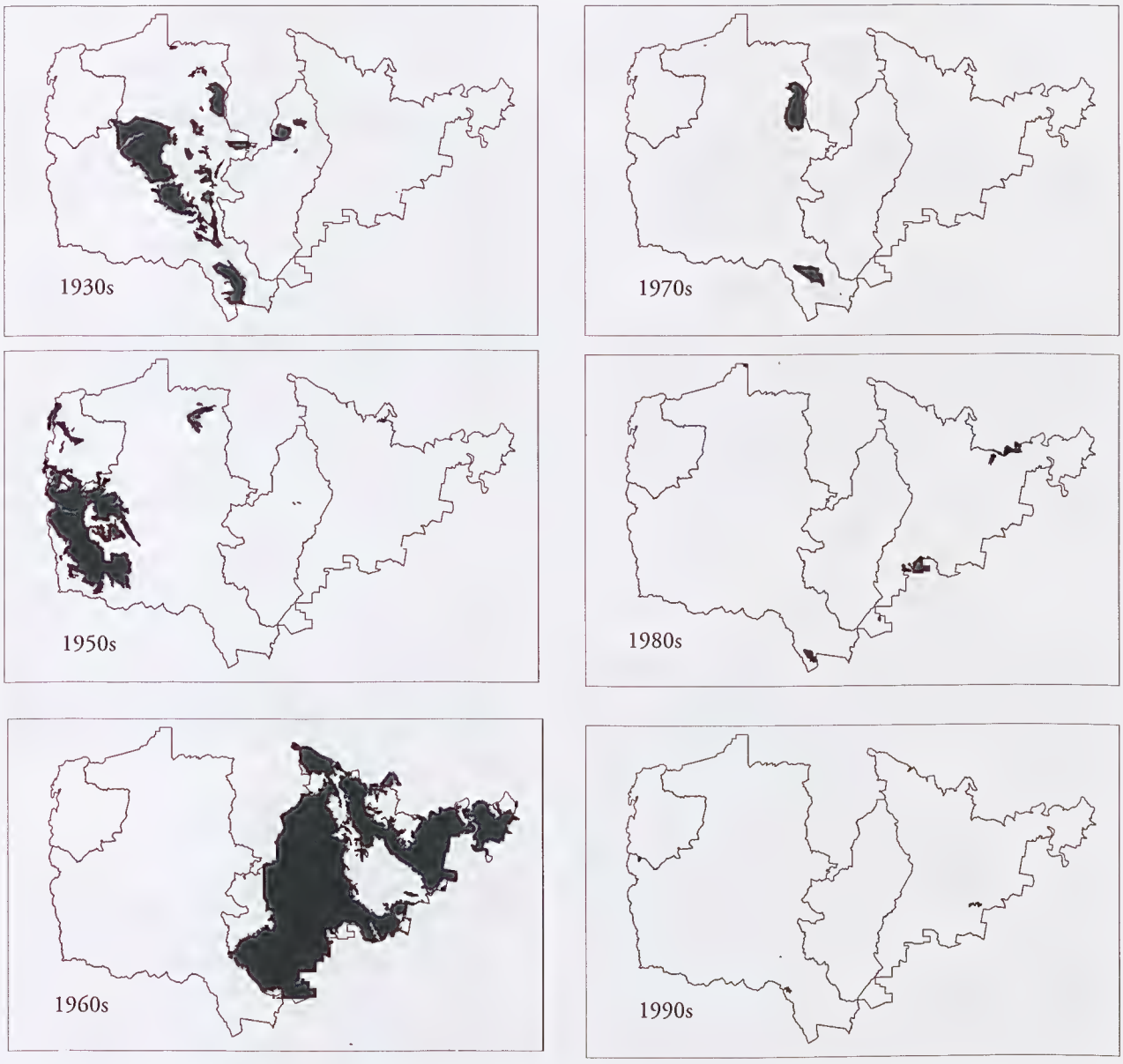

FIG. 2 — Approximate areas burnt in different decades. Due to the limitations of this study, the areas burnt are likely to be underestimated. No fires were recorded from the 1940s; see figure 1 for a more detailed map of the study area.

Eldon Range, Lake Ewart, Murchison River and the area now covered by Lake Mackintosh. Kirkpatrick & Whinam (1988) suggest (from banksia node counts) that there is evidence over most of the Lake Ewart and Dome Hill area of at least one fire event in the 1950s. They also suggest that some coniferous heath on both Eldon Bluff and Dome Hill indicates that parts of these areas have not been burnt for a considerable number of years. One of the fire boundaries mapped in the present study suggests that the southern, lower slopes of Dome Hill burnt between 1947 and 1953 but that the upper slopes to the north did not.

Corbett (1995) mapped the boundary of the 1960–61 fire where it occurred in the part of the Central Plateau Conservation Area that is in the WHA. Additional areas were mapped as burnt near Lake Laura, on the Traveller Range and adjacent to Lake St Clair by the present study. They may also have burnt in 1960–61.

There is strong evidence from both anecdotal and government records that the 1960–61 fires were deliberately lit by highland graziers in order to clean out thick vegetation and promote green-pick for sheep and cattle grazing. However, it is worth noting that most of the area within which the 1960–61 fires were lit was outside the areas that were approved for grazing at that time (V. Dell pers. comm.).

Until the 1960s, grasslands and sedgelands in Cradle Valley were burned at relatively frequent intervals (Kirkpatrick & Balmer 1991). However, site ageing from around Cradle Valley suggests that these fires were restricted to the valley floor and did not burn the surrounding slopes. The plains near Lake Caruthers also appear to have been patchily burnt just before 1953. These fires must have been quite localised, as site ageing slightly north of Mount Campbell indicates that area is long unburnt. Parts of the

Central Plateau also continued to be frequently burnt at this time. Jetson (1993) notes that, although these fires were meant to be low blazes that did not damage root systems, sometimes misjudgments were made that transformed them into raging infernos.

Fires occurred in the Cuvier Valley and part of the southern and western slopes of Mount Olympus in 1976. With the exception of this fire and the 1960–61 Central Plateau fire, no major fires were mapped post-1953.

Areas Burnt in Different Fires

The fires mapped in this study burnt in excess of 129 000 ha (table 1, fig. 2). The areas burnt in these fires has been laid over a vegetation map developed as part of the World Heritage Area Tactical Fire Management Plan (PWS 2000). This vegetation map was derived from the World Heritage Area vegetation mapping project (Corbett unpubl.) and the Resource Assessment Commission vegetation map (Kirkpatrick & Brown 1991).

DISCUSSION

Over the past century, the fire history of the northern part of the WHA has been one of periods of few fires followed by a large fire. The major impacts on fire-sensitive vegetation mostly occurred during these large fires. This finding parallels the fire history of the southern part of the WHA (Marsden-Smedley 1998a), and has been reported to be the situation in other regions of the world (Luke & McArthur 1978, Christensen *et al.* 1989, Romme & Despain 1989).

Another major change in the region's fire history concerns the locations where fires occurred. Before the 1970s, fires occurred throughout the study area, while from the 1970s on, fires mostly occurred on the region's margins and major access routes (fig. 2).

During periods of few fires, it appears that in fire-adapted and fire-dependent vegetation the ratio of dead to live fuel, fuel continuity and total fuel load all increase. This results in fires burning over a wider range of conditions, with faster rates of spread and higher intensities than would otherwise be the case (Marsden-Smedley 1998b, Marsden-Smedley *et al.* 1999). This is particularly the situation in old-growth buttongrass moorlands (where site age exceeds about 35 years), which can act as a wick to carry fire rapidly through the landscape threatening other vegetation types, including fire-sensitive types (Marsden-Smedley & Kirkpatrick 2000).

One of the major questions arising from fire-history studies relates to interactions between the probability of fires starting, the characteristics of the vegetation's fuels when fires occur, and the likelihood that these fires will threaten fire-sensitive vegetation types. In regard to the probability of fires starting, it is highly likely that in the area covered by this study there has been a major reduction in the number and extent of unauthorised ignitions over the past 30 to 40 years. This reduction may be the result of a decline in the social acceptability of unauthorised burning-off of the bush. However, as the fuels age in the region's fire-promoting buttongrass moorlands and also in wet scrub and wet eucalypt forests, it is highly probable that they will carry fire over a wider and wider range of conditions. These increases in flammability may result in significant areas of fire-sensitive vegetation being burnt in the future. At present, we do not have sufficient information to comprehensively address these issues. However, it would be prudent to ensure that they are examined and that any new information is incorporated into the management practices for the region.

AUTHORS' NOTE

This paper is not a definitive study of fire in the northern part of the World Heritage Area of Tasmania. Only obvious fire scars have been mapped from the aerial photographs. The vegetation type and likely flammability of these areas has generally not been identified, which probably has resulted in the extent of fire being underestimated. This paper should therefore be viewed as a overview of fire in this area and be

TABLE 1
Area burnt and total area of different vegetation types

Decade	As	%	Rs	%	Bs, Ws	%	Wf	%	Rf	%	Total	%
1930s	7436	5.0	6072	32.9	5349	23.0	776	2.1	2677	3.5	22310	7.1
1940s	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1950s	2975	2.0	1717	9.3	3678	15.8	2379	6.4	2935	3.8	13684	4.4
1960s	69028	46.1	1441	7.8	324	1.4	12829	34.7	946	1.2	84568	27.1
1970s	1084	0.7	58	0.3	189	0.8	1064	2.9	927	1.2	3322	1.1
1980s	3462	2.3	157	0.9	8	0.0	1151	3.1	78	0.1	4855	1.6
1990s	219	0.1	0	0.0	55	0.2	0	0.0	0	0.0	274	0.1
Total burnt	84204	56.2	9445	51.3	9602	41.2	18198	49.2	7563	9.9	129013	41.3
Total area	149744	48.0	18429	5.9	23286	7.5	37019	11.9	76613	24.5	312263	–

As = alpine and subalpine heath; Rs = subalpine rainforest; Bs = buttongrass moorland; Ws = wet scrub; He = wet eucalypt forest; Rf = rainforest; total burnt = total area burnt in the fires mapped in this study; total area = the total area covered by this study; The figures on areas burnt in these fires should be taken as approximate areas only and used in conjunction with the fire descriptions.

used as a structure for subsequent information on fire history.

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(accepted 9 December 2002)

THE SPECIES OF *SPHAEROLOBIUM* (FABACEAE) IN TASMANIA

by Andrew C. Rozefelds, Ryonen Butcher and William Murray

(with one plate and three text-figures)

ROZEFELDS, A.C., BUTCHER, R. & MURRAY, W., 2002 (31.xii): The species of *Sphaerolobium* (Fabaceae) in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 136: 153–158. ISSN 0080–4703. Tasmanian Museum and Art Gallery, GPO Box 1164, Hobart, Tasmania 7001, Australia (ACR*, WM); Department of Plant Biology (Botany), University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia (RB). * Author for correspondence.

Two species of the globe pea *Sphaerolobium* occur in Tasmania: *Sphaerolobium minus* Labill. and *S. vimineum* Sm. Information on their morphology, distribution and conservation status in the state is discussed based primarily upon Tasmanian Herbarium (HO) records. The leaf morphology of both species is described.

Key Words: ***Sphaerolobium*, Fabaceae, Tasmania, morphology, distribution, conservation status.**

INTRODUCTION

The genus *Sphaerolobium* Smith is endemic to southern Australia and comprises 20 named species, 17 of which are restricted to southwest Western Australia. Of the species found in Western Australia, *S. vimineum* Sm. is widespread in wet habitats of the southwest corner from Perth to east of Esperance, and is also found in the eastern states (Crisp 1993, Butcher & Chappill 2001). Crisp (1993, 1994) showed that in eastern Australia three species of *Sphaerolobium* exist, although he recorded only a single species, *S. minus* Labill., from Tasmania. Butcher & Chappill (2001: 157) subsequently recorded *S. vimineum* from the state, and fieldwork by ACR has independently recognised that this species is present in Tasmania. In this paper the morphology of both species is described and notes on their distribution and conservation status in Tasmania are included. *Sphaerolobium* is often described as lacking leaves. However, specimens of both species have been collected with leaves and these features are included in the descriptions. Leaves are present in all species of *Sphaerolobium*, at least in juvenile plants and on new shoots, however, in most species the leaves are caducous (Crisp & Weston 1987). The nomenclature for both species follows Crisp (1993); the Tasmanian biogeographical zones are those of Orchard (1988).

TAXONOMY

Measurements are based upon alcohol-preserved plants of both species collected near Coles Bay, supported by size estimates of herbarium specimens. The colour notes are based on observations of living plants.

Key to species of *Sphaerolobium* in Tasmania (modified from Crisp 1993)

Calyx and bracteoles uniformly green-black *in vivo*; standard broadly obovate, wings equal to exposed keel; style with narrow membranous elliptical wing, tapering from apex down to 1/3–1/2 length of style ..... *S. minus*

Calyx and bracteoles green with small black spots *in vivo*; standard reniform, wings longer than and enclosing keel; style with membranous hemispherical wing, not abruptly tapering, and as broad as long and < 1/4 length of style ..... *S. vimineum*

Sphaerolobium minus Labill. (1805:108, t 138)

Type

Habitat in capite Van Diemen [Tasmania], *J.J. Labillardiere s.n.* (holo FL-W; iso BM, W) *fide* Crisp (1993) (pl. 1).

Description

Subshrub slender, to 60 cm high, usually leafless, green, glabrous, with woody perennating rootstock. *Stipules* absent. *Leaves* dark green and uniformly coloured, with pale margins becoming white when dried, alternate, shortly stalked almost sessile, ovate to lanceolate, concavo-convex and curved around stem, 2.5–4.8 mm long, 0.2–0.5 mm wide, acute, caducous, remnant leaf bases 0.4–1.0 mm long. *Inflorescence* of 20–80 paired axillary flowers, basipetally flowering, 20–130 mm long. *Pedicels* green–black with a few black flecks, 1.2–2.0 mm long. *Bracts* green–black, glabrous, narrowly ovate, 2.1–2.5 mm long, 1.1–1.3 mm wide, caducous. *Bracteoles* green–black, glabrous, ovate, 2.2 mm long, 1.5 mm wide, caducous. *Calyx* uniformly green–black, 3.0–3.5 mm long, turbinate, tube 1.2–2.0 mm long, 50–80% as long as upper lip, upper lip formed by 2 adaxial/upper lobes fused along 80–90% of their length, 1.7–2.5 mm long and each lobe broadly ovate, lower 3 lobes narrowly triangular, 1.7–2.3 mm long. *Corolla* yellow or red and yellow; standard pure yellow, or with faint red, or broadly defined red region following veins for a short distance, surrounding ± domed eye towards the base of the standard, broadly obovate, 5.0–6.0 mm long, 5.5–6.0 mm wide, including a rectangular claw of 1.0–1.5 mm length, this without callosities, margins ± flat. Wings yellow infused with some red towards the base, rarely all yellow, ± obovate, 4.0–6.4 mm long, 1.7–2.7 mm wide, including a curved claw of 1.0–1.5 mm long, adaxial spur triangular, twisted, the apex of the blade rounded. Keel yellow with red apex, or all yellow rarely, ± equal to the wings, 4.5–6.0 mm long, 2.0–2.7 mm wide, including a

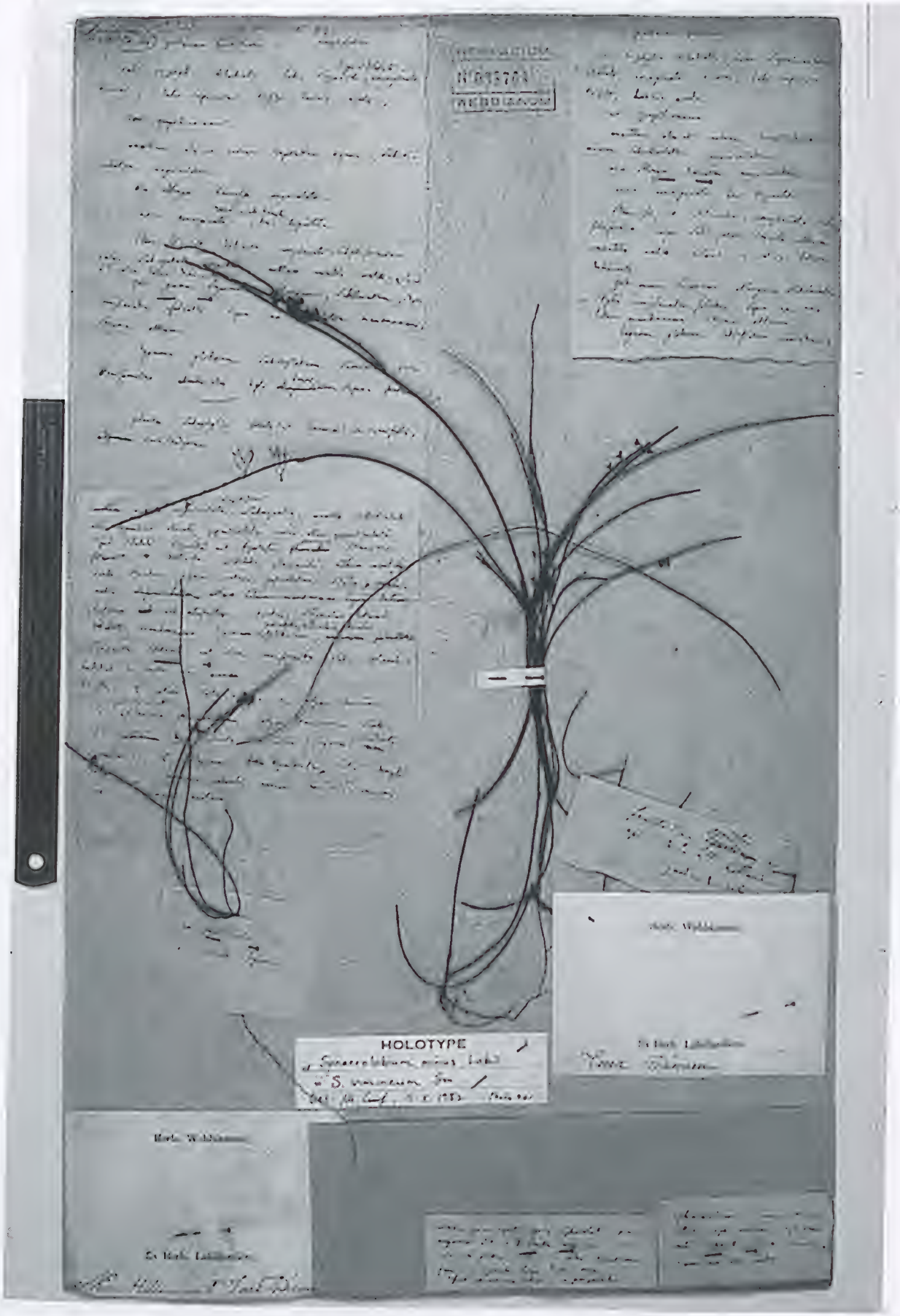

PLATE 1
Holotype of Sphaerolobium minus *Labill. from the Herb. Webbianum (Florence).*

straight claw of 1.0–1.5 mm length, the blade pouched from the claw towards the adaxial edge, the apex obtuse and slightly upturned, the adaxial edge straight, adaxial spur triangular, the abaxial edge arcuate, angled downwards. *Stamens* with filaments 3.5–4.5 mm long; anthers ± oblong, versatile, dorsifixed, c. 0.5 mm long, c. 0.3 mm wide, with small dorsal appendages. *Gynoecium* 6.0–7.0 mm long including the stipe (1.0–1.5 mm long) and the style (3.5–4.0 mm long), ovary glabrous, style straight to about one-third of its length, geniculate and curved distally, twisted towards apex, stylar wing narrow, fringed, 1.8–2.2 mm long. *Pod* light golden-brown, ellipsoid, 3.5–3.9 mm long, 2.4–2.6 mm wide, the style persistent, strongly bent backwards towards pod. *Seed* uniformly orange-light brown, 1.7–1.8 mm long, 1.2–1.3 mm wide, ± ovate, laterally compressed, without an aril, testa smooth.

Common name
Common eastern globe pea.

Selected specimens examined
Tasmania: East Coast: Copping 42°09'S, 147°48'E, roadside, *J.Somerville s.n.*, 24 xi 1959 (HO12149); Cape Hauy Track, 43°09'S, 148°00'E, *G.Kantvilas s.n.*, 17 xi 1979 (HO506905); Milligans Hill, Schouten Island 42°18' 26"S, 148°16'13"E, *Eucalyptus* forest on dolerite, *Rozefelds 1912*, 14 xi 2000 (HO509311). North East: Pioneer, Gladstone Road, 41°04'S, 147°57'E, *Eucalyptus ovata* (*E. amygdalina*) low open woodland, *F.Duncan s.n.*, 15 xi 1980 (HO330025); Goulds Country, 41°14'S, 148°03'E, *A.Simson 630*, xi 1876 (HO512120); Near Turners Marsh, 41°16'S, 147°08'E, *A.Simson 2453*, x 1891 (HO512028). South West: Track to Southport Headland, 43°28'S, 146°59'E, coastal eucalypt/heath community, *Rozefelds 624*, 22 xi 1992 (HO323644). West Coast: Near Remine, 41°55'S, 145°10'E, buttongrass moorland, *S.J.Jarman s.n.*, 14 i 1984 (HO323150).

New South Wales: Central Tablelands. Near Carrington Falls on the Robertson-Jamberoo road, 34°37'S, 150°39'E, rather wet ground, alt. 2000 ft, *Eucalyptus* woodland, *M.Evans 2665*, 24 x 1967 (NSW263704, CANB, K, L, A, CHR, AD, US, E, BO, BISH).

South Australia: Region 7: Eyre Peninsula. Wanilla Conservation Park, 34°33'0"S, 135°43'15"E, west facing slope; white sand with ironstone pebbles near hill crest, *E. cladocalyx* woodland with tall understorey of *Leptospermum, Baeckea, Acacia gillii* and low understorey of *Hibbertia, Xanthorrhoea, Lepidosperma, Dillwynia, Adenanthos, Pultenaea, D.Hopton 218*, 26 x 1988 (CANB523515, AD).

Victoria: East Gippsland. Turn-off to Genoa Creek, 4.6 km W of Genoa on Princess Hwy, 37°29'05"S, 149°33'00"E, growing in a moist depression, margin of open *E. consideniana-E. globoidea-E. ignorabilis* forest with *Bossiaea prostrata, Comesperma ericinum, Sowerbaea juncea* and *Hibbertia empetrifolia, J.H.Ross 3517*, 23 x 1991 (CANB501745, HO303763, BRI, CBG, S, MEL).

Remarks
Flower colour is variable with some flowers all yellow, while others are yellow with red flecking.

Distribution and ecology
Sphaerolobium minus is sometimes sympatric with *S. vimineum* (cf *Rozefelds 2142 and 2139*) and often occurs in seasonally wet areas, but also tolerates drier conditions, e.g. in *Eucalyptus ovata* woodland (*Duncan s.n.*). It has been collected from almost all regions (*sensu* Orchard 1988) of Tasmania, except very high montane areas (fig. 1). On mainland Australia, *S. minus* has been recorded from New South Wales, Victoria, South Australia and Queensland (Butcher & Chappill 2001: 158); and, as in Tasmania, has been collected from a wide range of habitats, although it shows a preference for damp, peaty substrates. This species does not occur in Western Australia.

Flowering
October–January

Conservation
This species is widespread and common throughout the State (fig. 1).

Sphaerolobium vimineum Sm. in K.D. Koenig & Sims (1805: 509)

Type
Port Jackson, N[ew] S[outh] Wales, *J.White s.n.* 1793 (holo LINN: iso LIV) *fide* Crisp (1993).

Description
Subshrub slender, to 1 m high, usually leafless, green, glabrous, with woody perennating rootstock. *Stipules* absent. *Leaves* dark green with a few black punctate markings, with pale margins becoming white when dried, alternate, shortly stalked, linear–lanceolate to elliptical, slightly concavo-convex to almost flat in larger leaves, 3.5–6.5 mm long, 0.5–1.0 mm wide, caducous, remnant leaf bases about 1 mm long. *Inflorescence* of 15–60 paired axillary flowers, basipetally flowering, 20–180 mm long. *Pedicels* dark green with black punctate markings, 1.5–2.0 mm long. *Bracts* green with

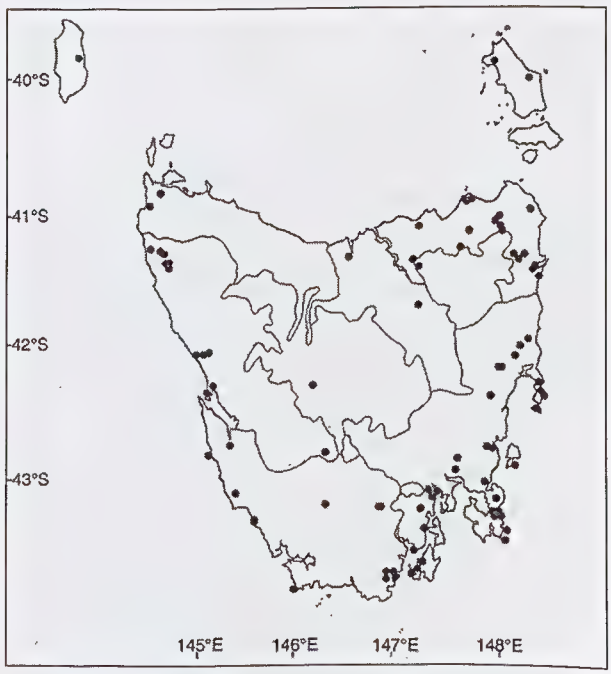

FIG. 1 — Distribution of Sphaerolobium minus *in Tasmania based upon Tasmanian Herbarium (HO) records.*

black punctate markings, ovate, 1.5–2.8 mm long, 0.6–2.0 mm wide, caducous. *Bracteoles* green with black punctate markings, ovate, 0.7–3.5 mm long, 0.5–1.9 mm wide, caducous. *Calyx* green with black punctate markings, 3.5–4.0 mm long, turbinate, tube 1.7–2.5 mm long, about equal to the upper lip, upper lip formed by 2 anterior lobes fused along 75–85% of their length, 1.5–2.7 mm long and each lobe broadly ovate, lower 3 lobes narrowly triangular to lanceolate, 1.5–2.5 mm long. *Corolla* yellow with some red; standard usually yellow with semicircle of dark red markings following veins for a short distance bordering a ± semicircular yellow 'eye', reniform, 4.6–7.0 mm long, 5.0–8.0 mm wide, including a rectangular claw of 1.0–1.5 mm length, this without callosities, margins curved, the blade shallowly emarginate, broadly auriculate. Wings yellow and broadly infused with some red towards the base, ± oblong, 4.2–6.0 mm long, 1.5–3.0 mm wide, including a curved claw of about 1.0 mm length, adaxial spur rounded, petal pouched outwards near base and apical margins deflected inward, the apex of the blade rounded. Keel pale yellowish green with red apex, shorter than the wings, 4.0–5.0 mm long, 2.0–3.5 mm wide, including a straight claw of 1.0–1.5 mm length, petal everted in basal half, with a small pouch on the lateral surface, the apex rounded, the adaxial edge curved and arcuate, adaxial spur triangular, the abaxial edge arcuate, angled downwards. *Stamens* with filaments 4.0–4.5 mm long, anthers broadly elliptical, versatile, dorsifixed, 0.4–0.65 mm long, 0.4–0.5 mm wide, without visible appendages on dorsal surface. *Gynoecium* 6.5–8.0 mm long including the stipe (1.0–1.5 mm long) and the style (3.0–4.5 mm long); ovary glabrous, style curved over ovary adaxially, with stylar wing ± hemispherical, 0.7–0.8 mm long. *Pod* light golden brown, ± globose, strongly angled on adaxial edge towards style and stipe, the style persistent, fully reflexed and pressed against pod, 3.1–3.2 mm long, 2.8–3.4 mm wide. *Seed* uniformly yellow-light brown, ovate, about 1.5 mm long, about 1.1 mm wide, laterally compressed, without an aril, testa smooth.

Common name

Eastern spotted globe pea

Selected specimens examined

Tasmania: North East: Bay of Fires Coastal Reserve, N of Sloop Lagoon, 41°12'S, 148°16'E, coastal heath in inundated areas, *Rozefelds 1468*, 3 xii 1999 (HO500846). East Coast: Road to Coles Bay, Freycinet Peninsula, 42°58'44"S, 148°14'19"E, in swampy areas, regrowth after fire, *Rozefelds 2139, 2146*, 25 x 2001 (HO516991, HO516993); edge of swamp, SW of Coles Bay, *Rozefelds 2158*, 26 x 2001 (HO516992); 1 km SW of Cape Naturaliste, on lagoon shore burned in 1981, with *Patersonia fragilis, Selaginella uliginosa, Pultenaea dentata, Boronia parviflora*, etc. 2-2.5 m alt., 40°52'S, 148°12'E, *A.Moscal 3428*, 13 x 1983 (HO88577).

New South Wales: Central Highlands, Hanging Rock Swamp, 5.6 km NW of Penrose Railway Station in the Penrose State Forest, 34°39'S, 150°10'E, swamp, *Leptospermum obovatum, L. juniperinum, Viola caleyana*, etc., *R.G.Coveny, P.Hind, T.James & P.Kodela 17196*, 17 xi 1994 (NSW402258, CANB, MEL, BRI).

Queensland: Wide Bay Military Training Area, about 8 km NNW of Tin Can Bay Township, alt. 3 m, 25°51'S, 152°59'E, deep "wallum" heath, *L.G.Adams 3607*, 22 ix 1980 (BRI430157, CANB).

Western Australia: 2 km NW of Frenchmans Bay Rd on La Perouse Rd, 35°5'6"S, 117°55'57"E, *Eucalyptus* woodland and dense *Agonis* scrub surrounding low lying swamp, with dense sedges, *Callistachys lanceolata, Patersonia* sp., *Anigozanthus* sp., *R.Butcher & J.Chappill RB 347*, 10 x 1997 (UWA); E side of Hay River Bridge, between river and Keith Rd., W of Denmark, 34°57'58"S, 117°27'55"E, flat swampy area in *Melaleuca* woodland with shrubland comprising *Sollya heterophylla*, species of *Andersonia, Dampiera, Conostylis, Brachysema* and sedges, *R.Butcher & J.Chappill RB 350* 10 x 1997 (UWA); Cape Le Grand National Park, 33°51'S, 122°27'E, sandy soil, *R.D.Royce 8701*, 21 x 1969, (PERTH2922088); Cape Le Grand National Park, 33°51'S, 122°27'E, sandy soil, *R.D.Royce 8830*, 22 x 1969 (PERTH2922339).

Remarks

Crisp (1993) suggested that eastern and western Australian collections of *Sphaerolobium vimineum* might represent different taxa. This supposition may have been based on the colour variation evident within this species across its range. Notes on herbarium specimens from New South Wales, Victoria and Queensland indicate that the flowers of *S. vimineum* are yellow to orange with red–brown markings, and this matches the few collections made in Tasmania to date, but flowers of this species from Western Australia are more commonly orangey-pink to red and the wings and keel are usually uniformly pink to red. Variation in corolla colour is evident across the southwest of Western Australia however, with some collections (*R.D.Royce 8701, 8830*) more closely matching eastern states material in being predominantly yellow–orange. The pattern of colour variation across the state has also been observed in other Western Australian species of *Sphaerolobium*, e.g. *S. drummondii* Turcz., *S. macranthum* Meisn., *S. medium* R. Br., *S. grandiflorum* R. Br., *S. daviesiodes* Turcz. and *S. racemulosum* Benth., and is not felt to be consistent enough for the colour forms to warrant formal taxonomic recognition (Butcher & Chappill 2001).

Distribution and ecology

The species has rarely been collected in Tasmania and is known only from swamps and the edges of lagoons in the northeast of the state (fig. 2).

Flowering

October–December

Conservation status

Although *S. vimineum* has been collected from swampy heath habitats in South Australia, Victoria, New South Wales and Queensland (Butcher & Chappill 2001: 157), the rarity of this species in these states has not been discussed, and collection information available from herbarium specimens indicates that abundance at any given site ranges from rare to locally common. In southwest Western Australia *S. vimineum* is widespread, but its distribution is patchy and corresponds with appropriate, seasonally wet habitat, with only a few collections made from drier sites and these in high rainfall areas. Much of the suitable habitat of *S. vimineum* in the Perth metropolitan area and on the Swan Coastal Plain has been destroyed by development and land-clearing for agriculture.

In Tasmania, this species has been collected from only four localities in the northeastern part of the state, and no

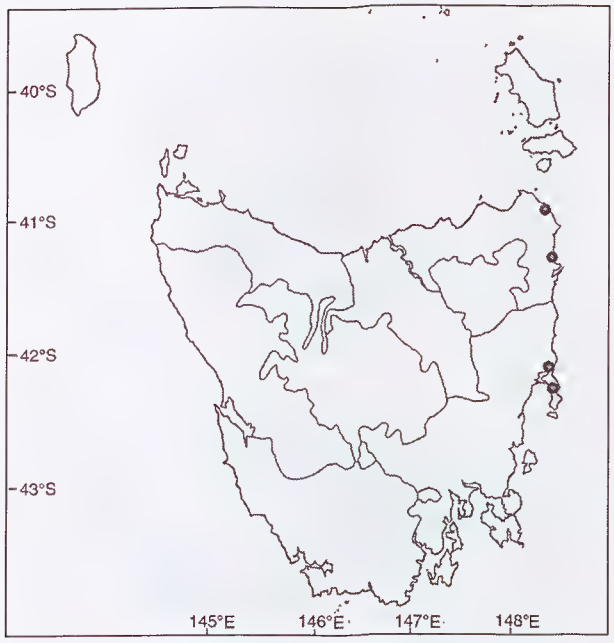

FIG. 2 — The distribution of S. vimineum *in Tasmania based upon Tasmanian Herbarium (HO) records.*

attempt has been made to accurately assess or survey the numbers of plants in these areas. As *Sphaerolobium* was considered to be represented by a single species in Tasmania (Curtis & Morris 1993, Buchanan 1999), flora surveys in the past are therefore likely to have uncritically referred all records of the genus to *S. minus*. The few known herbarium collections, the limited geographical extent of the species in Tasmania, the specialised habitat requirements and the fragmented distribution of the species would suggest that *S. vimineum* requires listing under the Tasmanian *Threatened Species Protection Act* 1995. While adequate information on the distribution of the species is currently not available, a conservation status of 'rare' under the Act is considered appropriate. A higher conservation rating may be required once field surveys have been undertaken to assess both population size and distribution of *S. vimineum* in Tasmania. As in Western Australia, land-clearing and development and the drainage of swamps for agriculture and pasture have probably resulted in the loss of suitable habitat, and may represent an ongoing threat to the species in the future.

DISCUSSION

Flowering specimens are needed to accurately distinguish between *Sphaerolobium minus* and *S. vimineum*. *Sphaerolobium vimineum* differs from *S. minus* most noticeably in the spotted appearance of the calyx, in that the standard is almost twice as wide as long, and that the wing petals enclose the keel (Fig. 3A, B, F, G). In addition, the wing on the style is hemispherical in *S. vimineum*, while in S. *minus* it is narrow and tapers down from the apex (Fig. 3C, H). Observations of *S. vimineum* and other species in the genus also indicate that leaves are present on all new growth but fall before flowers are fully formed in the axils and so are rarely collected (Crisp & Weston 1987). In a few herbarium specimens available the leaves of *S. minus* are ovate to lanceolate and uniformly coloured while those of *S. vimineum* are more elliptical and dark green with a few black punctate markings (fig. 3D, E, I, J). It is, however, possible to find both broadly elliptic and linear-lanceolate leaves on a single specimen of *S. vimineum*.

Sphaerolobium vimineum has only been collected from northeastern Tasmania (fig. 2). This region is an interesting biogeographical zone as it includes a large number of species that are shared with mainland Australia, and that reach their southern limit in this area. Species restricted to northeastern Tasmania, which also occur on mainland Australia, include *Caustis pentandra, Dockrilla striolata, Drosera glanduligera, Eucalyptus sieberi, Hydrocotyle callicarpa, H. capillaris, Leionema bilobum, Lepidosperma forsythii, L. viscidum, Muehlenbeckia adpressa, Pseudanthus ovalifolius, Ricinocarpus pinifolius, Sphaerolobium vimineum, Thryptomene micrantha, Villarsia exaltata, Viminaria juncea* and *Zieria littoralis*. The northeastern corner of the state could be interpreted as a refugium for species, such as *S. vimineum*, that may formally have been more widespread. Alternatively, lower sea levels at various times in the Quaternary, including during the Last Glacial, led to the formation of a land bridge between mainland Australia and northern Tasmania (Macphail 1979, Kirkpatrick & Fowler 1998; G. Jordan pers. comm. 2002). It is equally plausible that some of these species may have invaded this region during drier periods, or that there could have been a bi-directional movement of species during drier periods in the Quaternary, assuming suitable and/or continuous habitat conditions existed.

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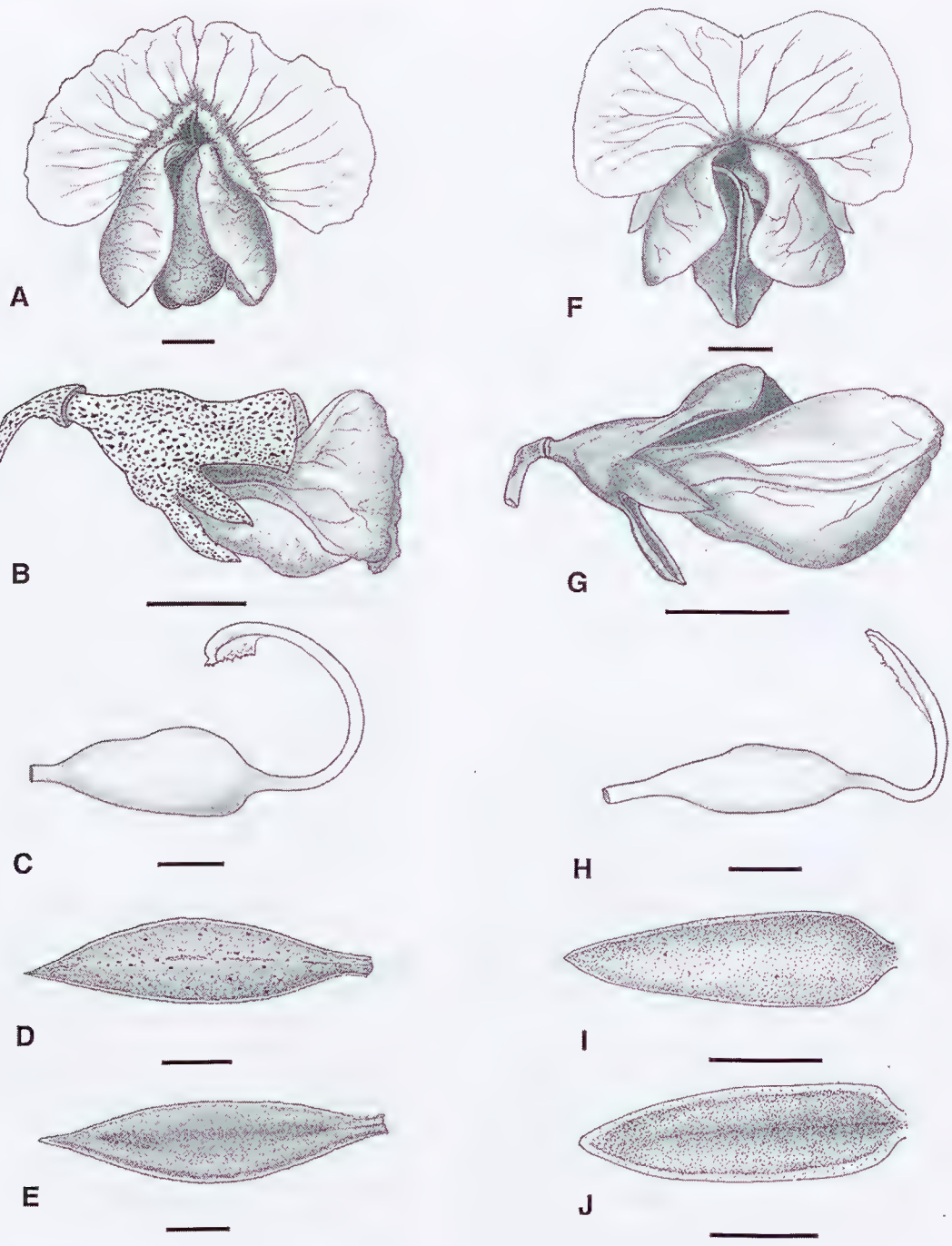

FIG. 3 — Sphaerolobium vimineum *Smith.* (A) *flower showing shape of standard;* (B) *flower with standard removed displaying conspicuously speckled calyx and wings enclosing the keel;* (C) *gynoecium;* (D) *leaf, adaxial view;* (E) *leaf, abaxial view. F–J.* S. minus *Labill.* (F) *flower showing shape of standard;* (G) *flower with standard removed displaying non-speckled calyx and wings equal to the keel in length;* (H) *gynoecium;* (I) *leaf adaxial view;* (J) *leaf abaxial view.*

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(accepted 9 December 2002)

WATER QUALITY IN KARSTLANDS AT MOLE CREEK, TASMANIA

by Rolan Eberhard and Ian Houshold

(with seven tables, one text-figure and two appendices)

EBERHARD, R. & HOUSHOLD, I., 2002 (31:xii): Water quality in karstlands: a reconnaissance survey at Mole Creek, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 136: 159–172. ISSN 0080–4703. Department of Primary Industries, Water and Environment, Nature Conservation Branch, GPO Box 44, Hobart, Tasmania 7001, Australia.

Samples from 28 sites at Mole Creek were analysed for a range of water quality indicators. Low or negligible bacterial counts were obtained for sites with mainly forested catchments; cleared catchments gave more variable and generally higher results. Higher turbidity and nitrate levels were recorded in cleared catchments, suggesting increased erosion and nutrient loading of streams. A comparison of water quality parameters at streamsinks and related springs shows that the karst aquifer is not an efficient water purifier. Rapid capture of surface run-off via solutional openings, coupled with the pipe-like efficiency with which karst conduits transfer the water, constrains the potential for the karst aquifer to ameliorate water pollution problems. This connection between surface and underground environments is a key consideration for sustainable land management in karstlands. We conclude that karst aquifers have more in common with surface streams than non-karstic ground-water systems, in terms of their water purification properties. Water from two bores was found to be relatively free of microbiological pollution, despite being located in disturbed catchments. This suggests that ground-water sourced from bores is less affected by activities at the surface, although further work is required to confirm this.

Key Words: karst, water quality, coliforms, ground-water, geoconservation, land management, Mole Creek.

INTRODUCTION

Protection of water quality in karstlands is a significant health and environmental issue (Ford & Williams 1989, Gillieson 1996, Drew & Hotzl 1999). Ground-water circulation in karst typically involves integrated networks of solutionally enlarged conduits, including cave systems, with high hydraulic conductivity. Pollution from point inputs and diffuse sources entering karstic conduits can rapidly contaminate aquifers, threatening ecosystems and creating hazards for human health. These problems can be compounded by a range of practices, such as allowing stock access to streams with resultant fouling of waterways, land application of chemicals for agricultural, silvicultural and other purposes, inappropriately sited and maintained septic and grey-water systems and use of sinkholes and caves for disposal of waste including animal carcases.

Tasmania's karstlands are developed primarily in folded and faulted Ordovician limestones and Precambrian dolomites that occur across a spectrum of physiographic contexts ranging from coastal to alpine. The land use setting of the karsts encompasses forestry, agriculture, mining and urban settlement as well as essentially undisturbed wilderness in Crown reserves. There are few data on the effects of the various land uses on water quality within Tasmanian karst systems, although attention has been drawn to some unsustainable practices (Kiernan 1984, Houshold 1995, Eberhard 2001).

The Mole Creek karst is located on the lower slopes of the Great Western Tiers between Liena to the west and Golden Valley to the east, in the catchments of the Mersey and Meander rivers (fig. 1). Annual rainfall is 1000–1100 mm at Mole Creek township (240 m asl) but probably reaches 1700–1800 on the Great Western Tiers (1200–1300 m asl). The karst is characterised by well-developed and complex subterranean drainage involving numerous caves, streamsinks and springs (Brown & De Vries 1958, Burns & Rundle 1958, Jennings & Sweeting 1959, Jennings & James 1967, Kiernan 1984, Kiernan *et al.* 1994). Surface run-off is limited due to rapid infiltration of precipitation and stream capture by subterranean conduits. The majority of streams rising on surrounding non-karstic rocks sink underground shortly after crossing the geological contact at the limestone margins. Tracer studies indicate that ground-water transfer within the aquifer can be rapid. Flow velocities of 30–100 m/hr are probably typical for ground-water moving through solutionally enlarged conduits, although more rapid flows are known to occur at high discharges and/or where steep hydraulic gradients

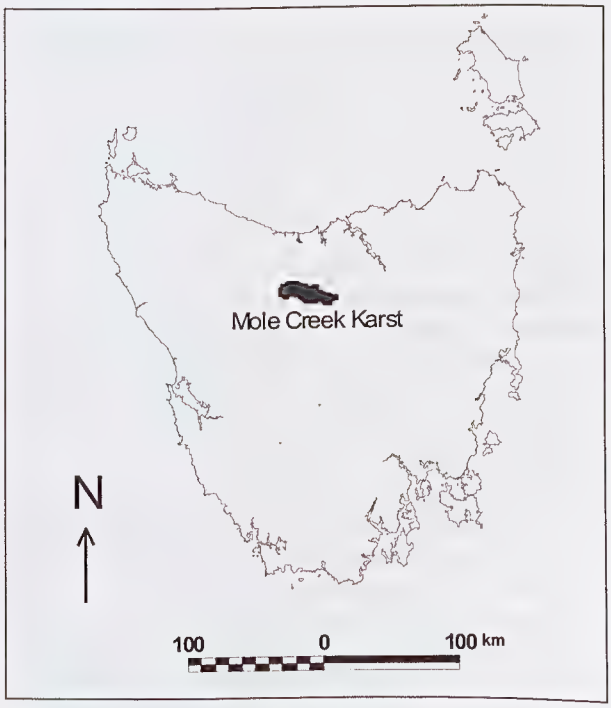

Fig. 1 — Location of Mole Creek karst, Tasmania.

exist. Under flood conditions, a flow velocity of 2181 m/hr was recorded for an underground stream that flows from Rubbish Heap Cave to Lynds Cave (Kiernan *et al.* 1994). The speed of ground-water transfer within the aquifer, and the fact that this often occurs through caves and cavities which function as efficient pipes, suggest a greatly reduced potential for natural remediation of ground-water pollution problems in comparison to non-karstic aquifers.

The Mole Creek area is subject to a range of land uses including agriculture, forestry, urban settlement and conservation reserves. Dairy operations are a major component of local agricultural production. The principal township is Mole Creek (population 256). Although the township is supplied by surface run-off water piped from the Great Western Tiers, ground-water is an important supply source for many households and farms. Some houses are entirely dependent on the karst aquifer, which is sourced at springs or bores. Water is also diverted from natural sinking points by artificial channels to supply sites lower in the catchment. An export-based mineral water bottling enterprise is based at a karst spring near Caveside.

Previous studies of water quality at Mole Creek imply that some waters are relatively polluted with respect to bacteriological parameters (Kiernan 1984, Dept. Agriculture unpubl. data 1989, Meander Valley Council unpubl. data 1998–2001). Kiernan (1987) observed that "a potentially significant pollution problem may exist [at Mole Creek] and that there is a need for more detailed scrutiny and more careful management". Kiernan (1992) states that Tasmania's most heavily polluted spring is at Mole Creek.

Water quality is generally discussed in terms of its suitability for consumption and use by humans, for food production or aquatic ecosystems (National Water Quality Management Strategy 2000). While these are clearly significant issues, water quality also impinges on weathering processes and soil–water interactions. As such, water quality can be a key issue in managing for sustainable land management and the protection and maintenance of natural geodiversity (DPIWE 2001). This issue is particularly pertinent in karstlands due to the importance of solutional process in shaping the geomorphology, including secondary carbonate deposition in the form of tufa and speleothems. At Croesus Cave, an outstanding sequence of rimstone dams, which have been deposited along a reach of cave streamway, are now being eroded by chemically aggressive waters (Eberhard 1993). The trigger for this seemingly recent change in stream geochemistry requires further investigation but Croesus Cave clearly illustrates the importance of water quality as a management issue for geodiversity protection in karstlands. Karst caves are also susceptible to degradation through human-induced changes to natural rates of erosion and deposition of clastic sediments. Many caves in cleared catchments at Mole Creek show evidence of post-settlement sedimentation by fluvially transported clays and soils.

The present survey of water quality was undertaken for the Natural Heritage Trust Mole Creek Karst Strategy, a project to promote sustainable land use practices at Mole Creek, taking account of a range of issues related to the karstic setting (Eberhard & Houshold 2001). While some water quality data were available from previous studies, further sampling was considered worthwhile to clarify the extent of possible ground-water pollution problems, and to provide a more systematic basis for assessing anthropogenic impacts on the karst system. The water quality program was seen as potentially useful in prioritising resources for stream protection and restoration works within the catchments of high conservation value caves.

PREVIOUS STUDIES

Microbiology

Data are available for 51 previous samples collected in the Mole Creek karst catchment (tables 1–3).

Physical and Chemical Parameters

A summary of data for selected physico-chemical water quality parameters at Mole Creek is presented in table 4. The comprehensiveness of the assays varies considerably between samples, some of which were analysed for only one or a few parameters (e.g. pH, conductivity). This sample set is biased in favour of lower catchment sites, particularly springs. Data for some parameters are based on a very limited sampling.

Methods

Thirty water samples were collected at 28 sites around Mole Creek, Liena, Caveside and Chudleigh in June and July 2001. The sites include nine streamsinks (i.e. point inputs to the karst aquifer, typically surface streams that sink underground at cave entrances), eight karstic springs, nine surface streams and two bores. The surface streams are fed by a variety of sources including karstic springs and surface run-off. The sample sites can be grouped as follows:

- Streamsinks in mainly forested catchments (five sites): Execution Creek, Sassafras Creek (upper sink), Grunter Creek, Lobster Rivulet (upper sink), Rubbish Heap Cave.
- Streamsinks in partly cleared catchments (four sites): Sassafras Inflow, Howes Cave, Circular Ponds, Mersey Hill uvala.
- Springs in mainly forested catchments (two sites): Marakoopa Creek, Lynds Cave.
- Springs in partly cleared catchments (six sites): Lime Pit, Bachelors Spring, Kubla Khan Efflux, Scotts Rising, Wet Cave, Mersey Hill Cave.
- Surface streams (nine sites): Ration Tree Creek, Sassafras Creek (Ugbrook), Mole Creek (Den Road), Lobster Rivulet (Swimming Pool), Lobster Rivulet (Caveside), Lobster Rivulet (Chudleigh), Lobster Rivulet (Lobster Falls), Mersey River (Olivers Road), Mersey River (Kellys Bridge).
- Bores (two sites): Liena, Caveside.

Although classified above as mainly forested or partly cleared, the sites span a continuum from relatively undisturbed native forest to intensively farmed agricultural land. All the sites have been subject to some level of anthropogenic disturbance. With the exception of Mersey River (Olivers Road), the surface streams and bores sample sites are mainly cleared catchments. The streamsinks sampled can be considered surrogates for surface streams in undisturbed catchments.

Where possible, samples were obtained at streamsinks and springs for which a direct hydrological connection is known to exist, through cave exploration or water tracing studies. These samples can be used to compare variations

TABLE 1
Bacterial data for Mole Creek water samples*

	Total coliforms (per 100 mL)	Faecal coliforms (per 100 mL)	Faecal streptococci (per 100 mL)
Kubla Khan Cave	110	4	3
Soda Creek	2800	20	1
Lime Pit	2700	20	16
Little Trimmer Cave	0	0	0
Marakoopa Cave (Long Creek)	300	3	3
Marakoopa Cave (Short Creek)	70	2	3
Sassafras Creek ('spring j')	30000	2800	2800
Sassafras Creek ('spring i')	1100	650	1300
Sassafras Creek ('spring e')	200	30	70
Sassafras Creek ('main creek above spring e')	2900	280	80
Cowshed pool – G. Howe	33000	14000	2500
Red Water Pot	8000	4000	14000
Mersey Hill Cave	200	80	100
Den Cave	500	80	60
Scotts Rising	500	40	13
Wet Cave	240	4	7
Honeycomb I Cave	1300	40	110

* The samples were collected in June and August 1984, and reported by Kiernan (1984).

TABLE 2
Bacterial data for Mole Creek water samples*

	Standard Plate Count (per mL)		Presumptive Total Coliforms (per 100 mL)	Presumptive *E. coli* (per 100 mL)	Faecal Streptococci (per 100 mL)
	36°C	20C			
Wet Cave	1700	1600	<4	<2	<2
Lynds Cave	4	81	96	<2	4
Lime Pit	2000	17000	520	130	22
Union Cave	15	66	<4	<2	<2
Sassafras Cave	180	7100	240	140	40
Mole Creek (at township)	2100	1600	900	580	100
Scotts Rising	620	980	20	25	20
Spring E	540	560	60	<5	<5

* Collected by the Department of Agriculture on 9 March 1989 (M. Hart, pers. comm.).

in water quality as streams pass through the karst aquifer, as at Rubbish Heap Cave, which flows to the Lynds Cave spring; Execution Pot, which flows to the Lime Pit spring; Grunter Creek and Howes Cave, which flow to Kubla Khan Efflux; Circular Ponds, which drains to Bachelors Spring; Sassafras Creek (upper sink) and Sassafras Inflow, which feed a series of karst springs upstream of the Sassafras Creek (Ugbrook) site (this site also lies downstream of the Circular Ponds–Bachelors Spring system); Mersey Hill uvala, which flows to Mersey Hill Cave; and Lobster Rivulet (upper sink), which is considered the principal source of Lobster Rivulet (Swimming Pool). Appendix 1 gives further information on the sites, including notes on their hydrogeological context and catchment integrity.

Discharge varied considerably between sampling dates, but on all occasions was subdued in comparison to typical winter conditions. Stream stages were substantially lower on 6 June 2001 than on subsequent collection dates. The intermittent Soda Creek Cave spring, which we had hoped to sample, remained dry throughout the collection period. Two sites (Bachelors Spring, Sassafras Creek at Ugbrook) were sampled twice, the second occasion being after heavy rain, to provide an indication of water quality variations with stage.

The samples were stored on ice in bottles supplied by the relevant laboratories, prior to delivery for analysis within 24 hours of collection. Total coliforms (TC), faecal coliforms (FC), *E. coli* and faecal streptococci (FS) were assayed at the NATA accredited Water Ecoscience Laboratory (then known as AWT) at New Town, Tasmania. Methods specified in Australian Standards AS4276.5-1995, AS4276.7-1995, AS4276.9-1995 were used. Analytical

TABLE 3
Summary of bacterial counts for Mole Creek karst sites and 15 non-karst sites within the Meander Valley Municipality, 1998–2001*

	Mole Creek above junction with Limestone Creek	Limestone Creek above junction with Mole Creek	Mole Creek below junction with Limestone Creek	Lobster Rivulet at Chudleigh	Non-karst sites monitored by MVC
Total coliforms(per 100 mL)					
Number of samples	9	9	9	9	149
Maximum	6300	7600	7400	4200	40540
Minimum	140	~980	460	210	12
Mean	~4710	~3650	~2750	~1040	~470
***E. coli* (per 100 mL)**					
Number of samples	8	8	8	8	123
Maximum	5300	4000	~3000	3800	3500
Minimum	92	270	76	140	<4
Mean	~1880	~1920	~1340	~800	~240
Faecal streptococci (per 100 mL)					
Number of samples	8	8	8	8	123
Maximum	1300	~1900	~980	2000	26000
Minimum	4	44	24	24	<4
Mean	~330	~410	~400	~350	~350

* Meander Valley Council (unpubl. data). Note that Council records refer to Mole Creek above junction with Limestone Creek as 'Mole Creek at township', Limestone Creek above junction with Mole Creek as 'Stoney Creek above junction', Mole Creek below junction with Limestone Creek as 'Stoney Creek below junction' and Lobster Rivulet at Chudleigh as 'Lobster Creek' (D. Donovan, pers. comm.).

TABLE 4
Summary of water quality data for streamsinks, springs and autogenic percolation waters ('cave drips') from previous studies at Mole Creek*

	Streamsinks	Springs	Autogenic percolation ('cave drips')
Temperature (°C)	9.8–11.0	9.0–10.4	9.4–9.7
Turbidity (NTU)	0–3	0–170	–
pH	5.5–7.44	6.99–8.61	8.1–8.3
Conductivity (mS/cm at 25°C)	84–290	160–493	310–495
Total hardness (mg/L as $CaCO_3$)	11.6–33	49.2–252	~140–~340
Bicarbonate alkalinity (mg/L as HCO_3)	17–42	90–325	87–320
Chloride (mg/L)	4.6	2.1–20	2.5–3.0
Sulphate (mg/L)	1.6–1.8	1.4–6.2	1.5–5.7
Calcium (mg/L)	3.0–8.3	26–84	23.5–96
Magnesium (mg/L)	1.3–2.9	2.1–12.0	4.0–31.5
Potassium (mg/L)	0.20–0.25	0.7–38	0.53–0.70
Sodium (mg/L)	3.0–3.25	2.6–14	3.6–4.2
Nitrate (mg/L)	–	0.2–1.0	–
Iron (mg/L)	–	0.005–0.2	–
Manganese (mg/L)	–	0.001–0.15	–
Cadmium (mg/L)	–	<0.0001–0.0005	–
Copper (mg/L)	–	<0.0001–<0.0005	–
Lead (mg/L)	–	<0.001	–
Zinc (mg/L)	–	<0.001–0.004	–
Sulphur (mg/L)	–	1–9	–
Boron (mg/L)	–	0.00–0.01	–
Molybdenum (mg/L)	–	0.00	–

*(Jennings & Sweeting 1959, Goede 1981, Kiernan 1984, Eberhard & Kiernan 1990, Eberhard unpubl. data 1991, Eberhard 1993, Dept Agriculture unpubl. data 1989, Spate & Holland 1990).

Services Tasmania undertook chemical analyses (except ammonia) in accordance with NATA requirements. The following parameters were assessed:

- Alkalinity by APHA Method 2320/4500-CO2;
- Anions by Ion Chromatography APHA Method 4110C;
- Ammonia by Ion Selective Electrode APHA Method 4500-NH3;
- Metals by APHA Method 3030/3120;
- Cations by APHA Method 3030/3120.

Temperature, pH and total dissolved solids (TDS) were measured *in situ* using WTW field pH and conductivity meters. The instruments were calibrated in standards supplied by the manufacturer before each pH and conductivity measurement.

Turbidity was measured *ex situ* using a Hach 2100P model optical principle turbidimeter. Samples were collected in polythene bottles and refrigerated for periods of days to weeks prior to analysis. As turbidity can change unless measured within 24 hours of collection (Chapman 1996), turbidity data obtained in this study should be considered indicative only.

RESULTS

Bacterial results for all samples are presented in tables 5 and 6. Physical and chemical results are summarised in table 7. The complete data are provided in appendix 2.

DISCUSSION

Microbiology

The microbiological data show considerable variation between sites, with very low results recorded at the two bores, Rubbish Heap Cave and Mersey Hill uvala. Somewhat higher coliform levels were found at Sassafras Inflow, which yielded the highest microbiological counts in this study (560 TC, 350 FC, 280 *E. coli*, 650 FS per 100 mL). The majority of samples were found to contain only a few or tens of coliforms, in contrast with some high results obtained in previous studies. For example, a result of 30 000 TC per 100 mL is reported for a spring on Sassafras Creek by Kiernan (1984), who records coliform counts of the hundreds to thousands at several sites. In 1989, coliforms were found in some samples, but were below detection limits in others (Dept. Agriculture unpubl. data 1989). The 1998–2001 samples collected by Meander Valley Council cover a smaller number of sites but have the value of continuity over time. Orders of magnitude for bacterial counts in these data range from hundreds to thousands per 100 mL, with average values being 1000–5000 TC, 1000–2000 *E. coli*, and 300–400 FS per 100 mL.

The timing of samples with respect to rainfall events probably accounts for much of the variation between sample sets. In dry weather conditions TC, FC, *E. coli* and FS are generally detected only at low levels (<1 to 20–30 per 100 mL) in streams and inshore surface waters of lakes in undisturbed areas in Tasmania (Davies & Driessen 1997). Microbiological contamination of surface waters can be expected to increase following rainfall and persist for several days at hundreds or low thousands per 100 mL, but will tend to reduce within a few days (C. Garland pers. comm.). A similar effect is to be anticipated for ground-water samples collected from caves and springs in karstlands. The 1984 Mole Creek samples were all collected during heavy rain, which may explain some of the high results. Discharge conditions when the 1989 samples were obtained are unknown but may not have been high as sampling was undertaken in summer. In the present study, repeat samples for Bachelors Spring and Sassafras Creek (Ugbrook), show somewhat higher FC, *E. coli* and FS counts after heavy rain on 13 June 2001, but the increase is far from dramatic and TC levels are reduced in the later samples.

The 2001 samples indicate substantial differences in microbiological levels between forested and cleared catchments (table 6). Streamsinks and springs in forested catchments were found to contain low or negligible bacterial contamination. In contrast, streamsinks in cleared catchments gave results ranging from negligible at Mersey Hill uvala, to more substantial counts (tens to hundreds) at the three other sites. Results for springs in cleared catchments are also mostly very low (≤10 TC, FC, *E. coli* or FS per 100 mL), although a higher count was obtained at Bachelors Spring. Results for surface streams in cleared catchments range from nil to hundreds of coliforms, as at sites along the middle to lower reaches of Lobster Rivulet. In some cases there is evidence of a downstream increase in coliforms in surface streams (e.g. Sassafras Creek, Mole Creek), but the pattern is not universal (e.g. Lobster Rivulet).

Comparison of the 2001 results with data obtained by the Meander Valley Council at 15 non-karstic sites elsewhere in the municipality indicates that Mole Creek is not exceptional with respect to bacterial pollution, falling within the range of results recorded in other catchments (table 3). However, these data indicate that average TC levels at Mole Creek were 2–10 times higher than the non-karstic sites, while mean *E. coli* levels are 3–8 times higher. Mean FS levels at Mole Creek are commensurate with those recorded at the non-karstic sites. The Lobster Rivulet (Chudleigh) result obtained in the present study falls towards the lower end of the range of results recorded at the same site by Council in 1998–2001. The mean and maximum values in samples collected by Council are one and two orders of magnitude higher than the results obtained in the present study. This result and the generally higher coliform levels recorded in 1984 and 1989 suggests that the present study sampled outside periods of peak coliform levels, highlighting the constraints of characterising water quality from small sample sets (Quinlan 1988). The council data for the Mole Creek area show considerable variation in coliform levels over time.

As mentioned above, caves and subsurface conduits generally have far less capacity for remediation of anthropogenic water quality problems than do non-karst ground-water systems. A common misconception is that water emerging from springs has been purified through a long residence time underground. However, microbiological data for Mole Creek indicate that ground-water systems here follow patterns observed in other karst systems in having only limited capacity to ameliorate problems introduced in source areas. Table 6 illustrates this point with regard to microbiological pollutants. Most of the caves and springs with higher coliform counts are hydrologically linked to streamsinks that also show significant coliform levels. The Mersey Hill uvala–Mersey Cave system and the Wet Cave–Scotts Rising system both

TABLE 5
Bacterial counts for Mole Creek water samples, June–July 2001

Site	Date	Total coliforms (per 100 mL)	Faecal coliforms (per 100 mL)	*E. coli* (per 100 mL)	Faecal streptococci (per 100 mL)
Ration Tree Creek	06/06/01	8	<1	<1	33
Liena bore	06/06/01	<1	<1	<1	<1
Rubbish Heap Cave	12/07/01	<1	<1	<1	<1
Lynds Cave	12/07/01	7	3	3	10
Lime Pit	06/06/01	4	2	2	<1
Execution Pot	06/06/01	4	3	3	3
Grunter Creek	13/06/01	7	7	7	10
Howes Cave	13/06/01	37	50	50	22
Kubla Khan Efflux	13/06/01	10	6	6	5
Marakoopa Cave	13/06/01	1	1	1	<1
Circular Ponds	13/06/01	310	230	230	110
Sassafras Creek (upper sink)	13/06/01	1	<1	<1	6
Sassafras Inflow	06/06/01	560	350	280	650
Sassafras Creek (Ugbrook)	06/06/01	260	27	22	68
Sassafras Creek (Ugbrook)	13/06/01	250	90	60	120
Bachelors Spring	06/06/01	460	16	16	17
Bachelors Spring	13/06/01	240	100	100	45
Mersey Hill uvala	12/07/01	<1	<1	<1	1
Mersey Hill Cave	12/07/01	39	39	39	2
Wet Cave	02/07/01	3	3	3	1
Scotts Rising	02/07/01	10	2	2	1
Mole Creek (Den Road)	02/07/01	210	90	90	58
Lobster Rivulet (upper sink)	02/07/01	6	3	3	<1
Lobster Rivulet (Swimming Pool)	02/07/01	160	100	100	49
Lobster Rivulet (Caveside)	01/07/01	200	44	44	20
Lobster Rivulet (Chudleigh)	01/07/01	70	40	40	9
Lobster Rivulet (Lobster Falls)	01/07/01	130	130	130	21
Caveside bore	01/07/01	1	<1	<1	<1
Mersey River (Olivers Road)	01/07/01	13	8	8	9
Mersey River (Kellys Bridge)	01/07/01	370	310	310	470

TABLE 6
Summary of microbiological results (100% range) for different classes of site, Mole Creek, June–July 2001

Class of site	Total coliforms (per 100 mL 0)	Faecal coliforms (per 100 mL)	*E. coli* (per 100 mL)	Faecal streptococci (per 100 mL)
Streamsinks (forested)	<1–7	<1–7	<1–7	<1–10
Streamsinks (cleared)	<1–560	<1–350	<1–280	1–650
Springs (forested)	1–7	1–3	1–3	<1–10
Springs (forested)	3–460	2–100	2–100	<1–45
Surface streams	8–370	<1–310	<1–310	33–470
Bores	<1–1	<1	<1	<1

TABLE 7
Range of results for physical and chemical water quality parameters, Mole Creek, June–July 2001

	Streamsinks (forested)	Streamsinks (cleared)	Springs (forested)	Springs (cleared)	Surface streams	Bores
Temp. (°C)	5.1-9.2	6.6-9.2	7.9-8.2	7.6-10.6	4.9-10.5	10.0-12.8
pH	5.18-6.98	5.90-7.96	6.65-7.89	6.44-8.18	6.56-7.60	7.24-7.35
TDS (mg/L)	29-60	39-139	113-191	73-380	23-339	345-383
Turbidity (NTU)	0.2-1.3	1.1-5.6	0.4-1.3	0.2-23.4	0.6-14.1	0.3-0.4
Alkalinity CO_3 (mg/L)	<1	<1	<1	<1	<1	<1
Alkalinity HCO_3 (mg/L)	<1-21	4-56	42-83	25-186	4-164	159-176
Bromide (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chloride (mg/L)	2.2-7.1	4.2-7.2	4.4-5.2	3.5-6.7	2.8-5.7	4.5-6.7
Fluoride (mg/L)	<0.02-0.05	<0.02-0.04	<0.02-0.09	<0.02-0.04	<0.02-0.03	<0.02-0.05
Nitrate (mg-N/L)	<0.03-0.12	<0.03-2.6	0.33-0.42	0.07-1.0	0.04-0.69	0.2-2.3
Nitrite (mg-N/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Phosphate (mg-P/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sulphate (mg/L)	0.34-5.9	1.6-5.2	2.5	1.3-3.5	0.65-5.4	1.5-1.9
Ammonia (mg-N/L)	<0.05-0.08	0.06-0.09	0.05	<0.05-0.09	<0.05-0.17	<0.05-0.18
Aluminium (mg/L)	0.032-0.682	<0.020-0.469	0.030-0.045	<0.020-0.566	<0.020-0.612	<0.020-0.051
Arsenic (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cadmium (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium (mg/L)	<0.001-0.001	<0.001-0.002	<0.001-0.001	<0.001-0.003	<0.001-0.002	<0.001
Copper (mg/L)	<0.001-0.002	<0.001-0.001	<0.001	<0.001-0.002	<0.001-0.00	<0.001
Iron (mg/L)	<0.02-0.537	0.022-0.308	0.024-0.037	<0.02-0.467	<0.02-0.745	<0.02
Manganese (mg/L)	<0.005	<0.005-0.018	<0.005	<0.005-0.007	<0.005-0.038	<0.005-0.02
Nickel (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001-0.001	<0.001-0.002
Lead (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc (mg/L)	<0.001-0.007	<0.001-0.001	<0.001-0.002	<0.001-0.016	<0.001-0.011	<0.001-0.01
Calcium (mg/L)	0.94-5.42	2.24-37.7	14.6-31.8	6.49-69.8	1.25-61.9	40.7-63.7
Potassium (mg/L)	<0.02-0.32	0.34-0.77	0.37-0.38	0.20-0.84	0.09-0.59	0.44-0.59
Magnesium (mg/L)	0.63-1.17	0.64-6.19	1.34-2.65	0.93-5.58	0.69-3.30	4.59
Sodium (mg/L)	1.05-5.30	2.99-5.95	3.36-3.71	1.89-5.66	1.23-4.74	2.81-3.53

show increases in coliform counts following transmission underground. This may best be explained by percolation water inputs from overlying paddocks, direct to cave streams via dolines. The Circular Ponds–Bachelors Spring, Sassafras Inflow/Sassafras Creek (upper sink)–Sassafras Creek (Ugbrook) and Grunter Creek/Howes Cave–Kubla Khan Efflux systems all show some attenuation; however, in comparison with non-karst systems this is minor. The Execution Pot–Lime Pit and Rubbish Heap–Lynds Cave systems both show very low levels of coliforms at both streamsinks and springs, as these systems have only minor disturbance. The Marakoopa Cave stream has negligible levels, presumably as a result of the relatively pristine state of the catchment within the Mole Creek Karst National Park.

In contrast to coliform levels at the karst springs, a lack of microbiological pollution was recorded at the two bores sampled. This is despite their locations within relatively disturbed and mostly cleared catchments. Adamski (2000) studied water quality in a carbonate aquifer in the mid-western USA and found significant differences between springs and wells in terms of many physico-chemical parameters. He accounts for this by suggesting that whereas the water from the springs generally flows rapidly through large conduits with minimum water–rock interactions, water from the wells flows through small fractures, which restrict flow and increase water–rock interactions. Adamski concludes that the springs are more susceptible to surface contamination than the wells. This could be true at Mole Creek, where the majority of springs are associated with well-integrated systems of solutionally enlarged conduits. However, the borehole at one of the Mole Creek sample sites (Liena) intersected sands and 40 mm rounded basalt cobbles in a cavity at a depth of 100 m below the surface. After heavy rain, the bore is reported to discharge turbid water. This strongly suggests a conduit-flow component at this site. Thus, it does not does appear to be universally true that bores at Mole Creek source water with prolonged ground-water residence times. Nevertheless, it seems that the bores could be less susceptible to ground-water pollution than springs, a possibility that warrants further investigation.

Physico-chemical Parameters

A major source of recharge to the Mole Creek karst aquifer is run-off from the surrounding non-karstic rock types, which are an important control on the physico-chemical quality of the ground-water. The alkalinity and pH of upper catchment sites indicate that the run-off is typically acidic

waters low in dissolved ions. This study found that run-off from Standard Hill, as sampled at Grunter Creek and Howes Cave, is considerably more acid than that from the Western Tiers, which is a major source area for the remainder of the karst. The tannin-stained appearance of run-off from Standard Hill suggests that acidity is boosted by drainage through peat soils. This effect is sufficiently pronounced to cause water emerging from karst springs at Kubla Khan Efflux and Bachelors Spring, which receive much of their flow from Standard Hill, to be slightly acidic. This is notwithstanding the buffering effect of contact with the limestone as the water passes through the aquifer. All other springs sampled in this and previous studies are about neutral or slightly alkaline, as would be expected due to carbonate dissolution processes within the aquifer. Levels of dissolved ions are low for all species analysed with the exception of calcium. The highest levels of calcium were recorded at springs, bores and surface streams fed primarily by springs. This conforms to accepted models of groundwater geochemistry within karst aquifers, whereby dissolution of the karstic bedrock releases calcium into solution (Ford & Williams 1989).

Two parameters show a relationship with catchment disturbance. Streamsinks and springs in forested catchments show low levels of turbidity (0.2–1.3 NTU), whereas turbidity at streamsinks, springs and surface streams in cleared catchments is more variable and often higher (0.2–23.4 NTU). The difference between the medians is statistically significant ($U=34$; $P<0.05$, Mann-Whitney U-test). Multiple samples along individual streams (Lobster Rivulet, Sassafras Creek and Mole Creek) all show increasing turbidity in the downstream direction, which would be consistent with a correlation between turbidity and the extent and intensity of disturbance. Of the ~80 results obtained by Eberhard (unpubl. data 1991), the highest levels of turbidity were recorded in disturbed catchments: Lime Pit (1–170 NTU), Scotts Cave (12–126 NTU), Soda Creek (0–10 NTU) and Sassafras Creek (8 NTU). The main cause of turbidity is the presence of fine suspended solids such as mineral particles derived from either erosion of soils in the catchment or erosion of stream banks (Gippel 1994).

The data also provide some evidence of a link between catchment disturbance and stream nutrient levels. Nitrate levels in forested catchments were found to fall in the range <0.03–0.42 mg-N/L, whereas a range of <0.03–2.3 mg-N/L was recorded in cleared catchments. The difference between the medians is statistically significant ($U=26$; $P<0.05$, Mann-Whitney U-test). Nitrate levels of 4.1–4.6 mg/L were recorded at Den Cave, Mersey Hill Cave and Den Spring by Kiernan (1984), but the significance of these data is difficult to assess. Nitrite and phosphate levels were below detection limits at all sites sampled in the present study. Sulphate levels show no obvious pattern, with the highest result (5.9 mg/L) being a sample from Execution Creek in a forested catchment. Ammonia levels are low in all samples (≤ 0.18 mg-N/L). Elevated nutrient levels could be expected in disturbed catchments due to various effects including application of fertilisers, increased stream temperatures due to reduced stream shading from vegetation, excretion by stock and effluent from septic systems.

The above discussion suggests that, with the probable exception of turbidity, the effects of catchment lithology dominate over catchment disturbance as a control on physico-chemical water quality parameters. However, a more detailed analysis of catchment effects is hampered by the small data set, precluding a more rigorous statistical comparison of different classes of site.

Comparison of physico-chemical data for streamsinks and related springs shows the following patterns:

- For the majority of systems, transmission through subsurface conduits has resulted in an increase in temperature, pH, TDS, turbidity, alkalinity, fluoride, nitrate, potassium, calcium and magnesium. Most of these increases are to be expected in karst systems in winter months. An interesting exception to this is the Mersey Hill uvala–Mersey Hill Cave system that shows an apparent decrease in calcium and magnesium at the same time as an increase in TDS and alkalinity. We suspect this is an error in either data collection or analysis.
- Increasing levels of nitrate are an as yet unexplained phenomenon in many karst systems, occurring in both natural and disturbed systems. Increases are, therefore, not necessarily linked with fertiliser inputs; however, where levels exceed more than one order of magnitude, this should be suspected (I. Houshold, unpubl. data). Although levels are low, nitrate concentrations in some springs at Mole Creek show more than order of magnitude increase over their related streamsinks. This suggests that application of artificial fertilisers and sources of ammonia, typical of many agricultural and urban systems, is having a detectable influence on the nutrient status of the groundwater. Data from overseas indicate that nitrate used in agricultural systems is readily transferred to karst aquifers (Nebbache *et al.* 2001).
- Levels of chloride, sulphate, aluminium, iron, zinc and sodium exhibit approximately equal distribution of increase and decrease in concentration, most likely reflecting specific catchment lithologies and soil types.
- In only a very few systems was a decrease in the concentration of a species recorded. The majority of decreases were for iron, aluminium and ammonia, all likely to be lost through oxidation. The iron and aluminium may be precipitated out of solution, and the ammonia rapidly oxidised to nitrate.

Most of the other metals analysed showed very low concentrations, which did not appear to change as a result of transport through cave systems.

CONCLUSIONS

Variations in water quality at Mole Creek are explicable in relation to natural factors such as soils and lithology within the catchment or whether the site is located upstream or downstream of the karst aquifer. Water quality is also affected by anthropogenic factors. Compared to sites in mainly forested, relatively pristine parts of the catchment, sites in partly cleared, disturbed parts of the catchment generally showed higher levels of microbiological pollution, turbidity and dissolved nitrate. The microbiological and physico-chemical parameters mostly show little attenuation after flowing through the karst aquifer for distances of hundreds to thousands of metres, implying that the karst aquifer has a limited or negligible effect in ameliorating water pollution. Rapid capture of surface run-off via solutional openings such as sinkholes, caves and streamsinks, coupled with the pipe-like efficiency with which karstic conduits transfer water to downstream outlets, evidently

constrain the adsorption of pollutants onto clays and organics or their breakdown through microbiological processes. This connectivity between surface and underground environments is a key consideration for sustainable land management in karstlands. We conclude that karst aquifers have more in common with surface streams, as opposed to non-karstic ground-water systems, in terms of their water purification properties. Bores may be an exception to the general pattern — the two sampled in this study did not show obvious signs of pollution, despite being located in disturbed catchments. The possibility that these sites are less affected by catchment activities warrants further investigation.

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APPENDIX 1
Details of sample sites

Site	Type	Altitude	Catchment lithology	Hydrological context	Catchment integrity
Ration Tree Creek	surface stream	320 m asl	Tertiary basalt Ordovician limestone	Ration Tree Creek drains the eastern slopes of Gads Hill above Liena.	A mixture of native forest and cleared land, previously used primarily for grazing but now subject to extensive eucalypt plantation development.
Liena	bore	320 m asl	Tertiary basalt Ordovician limestone The bore penetrates 70 m into limestone, which is overlain by 30 m of alluvium.	Bore is adjacent to Ration Tree Creek. The source area for the aquifer it taps is speculative at this time.	As above.
Rubbish Heap Cave	streamsink	420 m asl	Silurian sandstones and quartzites Permian and Triassic marine and terrestrial sediments Dolerite	Rubbish Heap Cave is the sinking point of Kansas Creek, which rises on Western Bluff. The cave stream flows to Lynds Cave on the Mersey River.	Largely native forest which has been selectively logged in past decades.
Lynds Cave	spring	300 m asl	As above plus Ordovician limestone	Rubbish Heap Cave is the major source for the cave stream at this site.	As above.
Lime Pit	spring	330 m asl	As above	Lime Pit is fed by the Execution Creek streamsink, probably supplemented by run-off from pasture areas traversed by the Mersey Forest Rd southeast of King Solomons Cave.	A mixture of native forest and cleared land. The native forest has been selectively logged; several tens of hectares were clearfelled in 2001. The cleared areas are currently used mainly for beef cattle production.
Execution Pot	streamsink	600 m asl	Silurian sandstones and quartzites Permian and Triassic marine and terrestrial sediments Dolerite	Execution Pot drains the northwestern slopes of Western Bluff. The cave stream flows to the Lime Pit spring.	Largely native forest which has been selectively logged in past decades.
Grunter Creek	streamsink	370 m asl	Ordovician sandstone	Grunter Creek drains the southeastern slopes of Solomons Dome. It flows to Kubla Khan Cave via the Grunter Catruns streamsinks.	Native forest. Some past logging.
Howes Cave	streamsink	370 m asl	Ordovician limestone Ordovician sandstone	Howes Cave drains the southeastern slopes of Solomons Dome. The cave stream flows to Kubla Khan Cave.	Immediate vicinity of Howes Cave is cleared land subject to mixed agriculture. Otherwise native forest with some past logging.
Kubla Khan Efflux	spring	340 m asl	As above	Outflow of Kubla Khan Cave, which receives flow from Grunter Creek, Howes Cave and other sources to the west of Grunter Hill.	Native forest in Crown reserves and State forest. Subject to some past logging. Also cleared land used for agriculture.
Marakoopa Cave	spring	420 m asl	Ordovician limestone Silurian sandstones and quartzites Permian and Triassic marine and terrestrial sediments Dolerite	Marakoopa Cave is a complex system that drains the northern slopes of Western Bluff. Two major tributaries within the cave are known as Long Creek and Short Creek. The combined flow of these was sampled downstream of the cave outflows.	Primarily native forest in Crown reserves. Marakoopa Cave is developed as a show cave.

APPENDIX 1 cont.

Site	Type	Altitude	Catchment lithology	Hydrological context	Catchment integrity
Circular Ponds	streamsink	300 m asl	As above plus Ordovician sandstone	Circular Ponds is a seasonally active sinking point for surface streams within the Mayberry basin. These are boosted by discharge from Marakoopa Cave, Kubla Khan Efflux, Gillam Creek and other sources. Circular Ponds drains to Bachelors Spring, a tributary to Sassafras Creek.	Native forest in Crown reserves and State forest. Cleared land at lower altitude, currently used for grazing, cropping and dairy production.
Sassafras Creek (upper sink)	streamsink	420 m asl	Ordovician limestone Silurian sandstones and quartzites Permian and Triassic marine and terrestrial sediments Dolerite	This is low stage sinking point of western branch of Sassafras Creek, in Baldocks Cave valley. Flows to Baldocks Cave and springs lower on Sassafras Creek.	Native forest in Crown reserves subject to past logging.
Sassafras Inflow	streamsink	290 m asl	As above	Sinking point of eastern branch of Sassafras Creek, which receives flow from karst springs at Cyclops Cave and Glowworm Cave. Drains to Sassafras Cave. Sampled at low stage sinking point in gravels several hundred metres upstream of the cave known as Sassafras Inflow.	Native forest in Crown reserves and private land subject to past logging. Cleared land at lower altitude, currently farmed for beef production.
Sassafras Creek (Ugbrook)	surface stream	230 m asl	As above	Sassafras Creek is fed by numerous springs between Sassafras Cave and Ugbrook. Bachelors Spring, which drains the Mayberry basin, contributes more than half the volume of the creek at Ugbrook.	Native forest in Crown reserves and private land subject to past logging. Cleared land at lower altitude, currently used for various agricultural purposes.
Bachelors Spring	spring	270 m asl	As above plus Ordovician sandstone	This spring is the major outlet for underground drainage originating in the Mayberry basin to the west. The Circular Ponds streamsink is one of several point input sources at Mayberry.	Native forest in Crown reserves and State forest. Cleared land at lower altitude, currently used for gazing, cropping and dairy production. The catchment includes a former local government waste disposal site in sinkholes, now covered over.
Mersey Hill uvala	streamsink	270 m asl	Ordovician limestone overlain by Tertiary basalt.	More southerly of two streamsinks within the uvala. Flows to Mersey Hill Cave.	Primarily cleared land used for mainly dairy production.
Mersey Hill Cave	spring	210 m asl	As above.	Main source of flow is streamsinks in the Mersey Hill uvala. Sampled at low stage spring in stream channel downstream of cave entrance.	Native forest and cleared land, the latter used mainly for dairy production.
Wet Cave	spring	310 m asl	Ordovician limestone Permian and Triassic marine and terrestrial sediments Dolerite	Wet Cave receives run-off from the Great Western Tiers. The main tributaries are streamsinks at Westmorland Cave and Kellys Pot. Below Wet Cave the water enters Honeycomb Cave, later emerging at Scotts Rising, the principal source of Mole Creek.	Native forest in Crown reserves and freehold. Lower in the catchment is cleared land, used mainly for dairy production.

APPENDIX 1 cont.

Site	Type	Altitude	Catchment lithology	Hydrological context	Catchment integrity
Scotts Rising	spring	270 m asl	As above	See Wet Cave above.	As above.
Mole Creek (Den Road)	surface stream	220 m asl	As above plus Ordovician sandstone Silurian sandstones and quartzites Tertiary basalt	See Wet Cave above. The smaller tributary of Limestone Creek joins Mole Creek at Mole Creek township. The Den Road bridge where the sample was obtained is downstream of the confluence.	As above plus urban settlement at Mole Creek township.
Lobster Rivulet (upper sink)	streamsink	390 m asl	Permian and Triassic marine and terrestrial sediments Dolerite	Lobster Rivulet rises on the Great Western Tiers near Nells Bluff. Depending on discharge conditions, all or part of the Lobster sinks underground into its bed at this point.	Essentially undisturbed native vegetation in Crown reserves.
Lobster Rivulet (Swimming Pool)	surface stream	290 m asl	As above plus Ordovician limestone	A mixture of surface run-off and karstic springs feed the Lobster Rivulet above the swimming pool. The sources of the various springs are speculative at this time, but may include water from Lobster Rivulet (upper sink).	Includes undisturbed native vegetation in Crown reserves (upper part of catchment), and freehold land comprising selectively logged native forest and cleared land used for agriculture, primarily dairy production.
Lobster Rivulet (Caveside)	surface stream	270 m asl	As above	As above. The Lobster's discharge at Caveside is probably supplemented by additional springs, which rise in extensive alluvial deposits that mantle the limestone in this area.	As above.
Lobster Rivulet (Chudleigh)	surface stream	260 m asl	As above plus Silurian sandstones and quartzites and Tertiary basalt	As above. Numerous springs supplement the Lobster's discharge between Caveside and Chudleigh. Water diverted from Westmorland Cave and the Mole Creek system via the 'Nine Foot' channel joins the Lobster above Chudleigh.	As above.
Lobster Rivulet (Lobster Falls)	surface stream	230 m asl	As above	As above. Lobster Falls is downstream of Chudleigh not far beyond where the Lobster crosses from the limestone onto surrounding non-karstic rocks.	As above, including plantation forestry and urban settlement at Chudleigh.
Caveside	bore	300 m asl	Ordovician limestone Permian and Triassic marine and terrestrial sediments Dolerite	The bore taps the karst aquifer several hundred metres to the west of Lobster Rivulet near the Caveside swimming pool.	Includes undisturbed native vegetation in Crown reserves (upper part of catchment), and freehold comprising selectively logged native forest and cleared land used for agriculture, primarily dairy production.
Mersey River (Olivers Road)	surface stream	300 m asl	Dominantly clastic sedimentary rocks (Parmeener Supergroup) and mudstone, siltstone and minor carbonate successions (Rocky Cape Group) and dolerite.	The Mersey River drains an extensive area to the south-west of Mole Creek. Its headwaters are located in the Cradle Mountain–Lake St Clair and Walls of Jerusalem National Parks. The sample site is at the point where Mersey first enters the karst catchment.	Catchment relatively undisturbed in upper parts, which are Crown Reserves. The river is subject to hydro-electric impoundment upstream of the sample site. Native forest logging occurs within the catchment.
Mersey River (Kellys Bridge)	surface stream	100 m asl	As above plus Ordovician limestone.	As above. The site is located just below the confluence of the Mersey River and Lobster Rivulet. No other tributary within the karst catchment joins the Mersey below this point.	As above plus land clearance, agriculture and urban settlement.

APPENDIX 2
Results for physical and chemical water quality indicators

	Date	Temp. (°C)	pH	TDS (mg/L)	Turbidity (NTU)	Alkalinity CO_3 (mg/L $CaCO_3$)	Alkalinity HCO_3 (mg/L $CaCO_3$)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg-N/L)	Nitrite (mg-N/L)	Phosphate (mg-P/L)	Sulphate (mg/L)	Ammonia (mg-N/L)
Ration Tree Creek	6-Jun-01	7.4	6.56	93	1.0	<1	32	<0.01	5.5	<0.02	0.51	<0.10	<0.10	0.77	0.17
Liena bore	6-Jun-01	10.0	7.35	383	0.4	<1	176	<0.01	4.5	<0.02	0.2	<0.10	<0.10	1.5	0.18
Lime Pit	6-Jun-01	9.5	8.18	380	0.2	<1	186	<0.01	5.5	0.04	0.63	<0.10	<0.10	3.6	0.09
Execution Creek	6-Jun-01	7.9	5.77	56	0.3	<1	2	<0.01	7.1	<0.02	<0.03	<0.10	<0.10	5.9	0.08
Bachelors Spring	6-Jun-01	10.6	7.17	356	0.3	<1	171	<0.01	4.8	0.04	0.55	<0.10	<0.10	3.5	0.06
Sassafras Creek (Ugbrook)	6-Jun-01	10.5	7.40	339	14.1	<1	164	<0.01	4.8	0.03	0.53	<0.10	<0.10	5.4	0.06
Sassafras Inflow	6-Jun-01	9.2	7.96	131	1.1	<1	50	<0.01	4.2	<0.02	0.09	<0.10	<0.10	5.2	0.06
Sassafras Creek (upper sink)	13-Jun-01	8.0	6.14	60	0.9	<1	21	<0.01	3.1	<0.02	0.11	<0.10	<0.10	1.2	0.06
Kubla Khan Efflux	13-Jun-01	8.8	6.44	112	6.2	<1	43	<0.01	4.3	<0.02	0.07	<0.10	<0.10	1.3	0.07
Marakoopa Creek	13-Jun-01	7.9	6.65	113	1.3	<1	42	<0.01	4.4	<0.02	0.42	<0.10	<0.10	2.5	0.05
Grunter Creek	13-Jun-01	8.1	5.18	35	1.3	<1	<1	<0.01	3.3	<0.02	<0.03	<0.10	<0.10	0.54	0.07
Howes Cave	13-Jun-01	8.7	5.90	39	1.4	<1	4	<0.01	4.4	<0.02	<0.03	<0.10	<0.10	1.6	0.08
Circular Ponds	13-Jun-01	9.1	6.43	139	5.6	<1	56	<0.01	4.4	<0.02	0.25	<0.10	<0.10	3	0.05
Bachelors Spring	13-Jun-01	10.2	6.71	263	23.4	<1	122	<0.01	4.7	0.04	0.53	<0.10	<0.10	2.8	<0.05
Sassafras Creek (Ugbrook)	13-Jun-01	10.1	7.01	260	1.1	<1	122	<0.01	4.6	0.03	0.52	<0.10	<0.10	2.2	<0.05
Mole Creek (Den Road)	2-Jul-01	9.0	7.49	202	3.4	<1	89	<0.01	4.5	<0.02	0.69	<0.10	<0.10	2.1	<0.05
Scotts Rising	2-Jul-01	8.8	7.34	154	1.0	<1	61	<0.01	3.8	<0.02	0.53	<0.10	<0.10	1.7	<0.05
Wet Cave	2-Jul-01	7.6	7.42	73	1.1	<1	25	<0.01	3.5	<0.02	0.23	<0.10	<0.10	0.34	0.05
Lobster Rivulet (upper sink)	2-Jul-01	6.3	6.65	29	0.3	<1	9	<0.01	2.2	<0.02	<0.03	<0.10	<0.10	1.1	<0.05
Lobster Rivulet (Swimming Pool)	2-Jul-01	8.4	7.23	60	1.5	<1	22	<0.01	2.8	<0.02	0.13	<0.10	<0.10	1.1	<0.05
Lobster Rivulet (Caveside)	2-Jul-01	8.1	7.56	62	2.2	<1	22	<0.01	2.8	<0.02	0.17	<0.10	<0.10	2.8	<0.05
Lobster Rivulet (Chudleigh)	2-Jul-01	9.0	7.57	102	4.9	<1	35	<0.01	4.8	<0.02	0.51	<0.10	<0.10	3.1	0.06
Lobster Rivuler (Lobster Falls)	2-Jul-01	8.6	7.60	117	4.7	<1	40	<0.01	5.7	<0.02	0.51	<0.10	<0.10	1.9	<0.05
Caveside bore	2-Jul-01	12.8	7.24	345	0.3	<1	159	<0.01	6.7	0.05	2.3	<0.10	<0.10	3	<0.05
Rubbish Heap Cave	12-Jul-01	5.1	6.98	43	0.2	<1	8	<0.01	4.8	0.05	0.12	<0.10	<0.10	2.5	0.05
Lynds Cave	12-Jul-01	8.2	7.89	191	0.4	<1	83	<0.01	5.2	0.09	0.33	<0.10	<0.10	3.4	0.07
Mersey Hill uvala	12-Jul-01	6.6	7.09	132	1.4	<1	32	<0.01	7.2	0.04	2.6	<0.10	<0.10	2.2	<0.05
Mersey Hill Cave	12-Jul-01	10.6	7.20	268	3.1	<1	119	<0.01	6.7	0.02	1	<0.10	<0.10	0.65	0.09
Mersey River (Olivers Road)	12-Jul-01	4.9	6.76	23	0.6	<1	4	<0.01	2.5	<0.02	0.04	<0.10	<0.10	2.1	0.07

APPENDIX 2 cont.

	Date	Aluminium (µg/L)	Arsenic (µg/L)	Cadmium (µg/L)	Cobalt (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Lead (µg/L)	Zinc (µg/L)	Calcium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)
Ration Tree Creek	6-Jun-01	139	<5	<1	<1	<1	<1	125	<5	<1	<5	<1	4.93	0.49	3.30	4.74
Liena bore	6-Jun-01	<20	<5	<1	<1	<1	<1	<20	<5	<1	<5	<1	63.7	0.44	4.59	3.53
Lime Pit	6-Jun-01	<20	<5	<1	<1	<1	<1	<20	<5	<1	<5	<1	69.8	0.84	3.32	3.68
Execution Creek	6-Jun-01	339	<5	<1	<1	<1	<1	131	<5	<1	<5	<1	1.76	0.32	1.04	5.30
Bachelors Spring	6-Jun-01	37	<5	<1	<1	<1	<1	28	<5	<1	<5	<1	66.6	0.61	3.53	3.51
Sassafras Creek (Ugbrook)	6-Jun-01	<20	<5	<1	<1	<1	<1	<20	<5	<1	<5	<1	61.9	0.59	3.23	3.46
Sassafras Inflow	6-Jun-01	<20	<5	<1	<1	<1	<1	22	<5	<1	<5	<1	16.2	0.77	1.65	4.61
Sassafras Creek (upper sink)	13-Jun-01	32	<5	<1	<1	<1	<1	22	<5	<1	<5	<1	5.42	0.21	0.88	2.29
Kubla Khan Efflux	13-Jun-01	566	<5	<1	<1	1	<1	467	<5	<1	<5	<1	17.7	0.33	1.41	3.10
Marakoopa Creek	13-Jun-01	45	<5	<1	<1	<1	<1	37	<5	<1	<5	<1	14.6	0.38	1.34	3.36
Grunter Creek	13-Jun-01	682	<5	<1	<1	1	<1	537	<5	<1	<5	<1	0.94	0.15	0.63	2.81
Howes Cave	13-Jun-01	469	<5	<1	<1	<1	<1	339	<5	<1	<5	<1	2.24	0.34	0.64	3.09
Circular Ponds	13-Jun-01	371	<5	<1	<1	<1	<1	308	<5	<1	<5	<1	21.8	0.53	1.59	2.99
Bachelors Spring	13-Jun-01	498	<5	<1	<1	<1	<1	344	<5	<1	<5	<1	46.6	0.61	2.57	3.25
Sassafras Creek (Ugbrook)	13-Jun-01	281	<5	<1	<1	<1	<1	201	<5	1	<5	<1	45.5	0.57	2.45	3.27
Mole Creek (Den Road)	2-Jul-01	110	<5	<1	<1	<1	2	78	<5	<1	<5	9	21.7	0.27	1.68	1.99
Scotts Rising	2-Jul-01	117	<5	<1	<1	<1	2	59	<5	<1	<5	8	15.9	0.24	1.50	2.00
Wet Cave	2-Jul-01	145	<5	<1	<1	<1	2	67	<5	<1	<5	16	6.49	0.20	0.93	1.89
Lobster Rivulet (upper sink)	2-Jul-01	75	<5	<1	<1	<1	2	26	<5	<1	<5	7	1.40	<0.02	0.74	1.05
Lobster Rivulet (Swimming Pool)	2-Jul-01	157	<5	<1	<1	<1	1	103	<5	<1	<5	5	5.27	0.13	1.04	1.38
Lobster Rivulet (Caveside)	2-Jul-01	170	<5	<1	<1	<1	1	120	<5	<1	<5	3	4.71	0.16	0.97	1.23
Lobster Rivulet (Chudleigh)	2-Jul-01	274	<5	<1	<1	1	1	232	6	<1	<5	8	7.73	0.40	1.54	1.75
Lobster Rivulet (Lobster Falls)	2-Jul-01	380	<5	<1	<1	<1	<1	307	13	1	<5	1	11.3	0.57	2.30	4.28
Caveside bore	2-Jul-01	51	<5	<1	<1	<1	<1	<20	20	2	<5	10	40.7	0.59	4.59	2.81
Rubbish Heap Cave	12-Jul-01	45	<5	<1	<1	<1	<1	<20	<5	<1	<5	2	2.60	0.15	1.17	3.02
Lynds Cave	12-Jul-01	30	<5	<1	<1	1	<1	24	<5	<1	<5	2	31.8	0.37	2.65	3.71
Mersey Hill uvala	12-Jul-01	186	<5	<1	<1	2	1	282	18	<1	<5	1	37.7	0.68	6.19	5.95
Mersey Hill Cave	12-Jul-01	330	<5	<1	<1	3	<1	310	7	<1	<5	3	7.93	0.64	5.58	5.66
Mersey River (Olivers Road)	12-Jul-01	81	<5	<1	<1	<1	1	68	<5	<1	<5	2	1.25	0.09	0.69	1.80
Mersey River (Kellys Bridge)	12-Jul-01	612	<5	<1	<1	2	3	745	38	<1	<5	11	19.2	0.53	2.74	3.24

BIOGENIC VOLATILE ORGANIC COMPOUNDS IN THE AMBIENT AIR AND PLANT EMISSIONS OF A TASMANIAN NATIVE FOREST, AND THE RELATIONSHIP BETWEEN EMISSION RATES AND ESSENTIAL OIL CONTENT

by Joseph P. Hutchinson and Adrian J. Blackman

(with eight tables and one text-figure)

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The biogenic volatile organic compounds (VOCs) in the ambient air of the Hobart Air Shed and in the emissions from selected Tasmanian native trees and understorey shrubs were measured. The emission rates were then related to the plants' essential oils content, which had been extracted by hydro-distillation. The VOCs in the ambient air of native forests have not previously been studied in Australia. This study used multi-adsorbent cartridge adsorption/thermal desorption and Gas Chromatography–Mass Spectrometry. The type, quantity, source and variation of the VOCs were investigated.

The concentration of VOCs in the atmosphere surrounding vegetation in the Hobart Air Shed was determined. In all, 129 compounds of eight classes were detected. Of these, 11 compounds were National Pollutant Inventory substances and 32 were considered biogenic; however, this estimate is conservative. The concentration of total VOCs in these ambient air measurements varied between 4.43×10^{-10} g L^{-1} and 3.04×10^{-9} g L^{-1} depending on the site sampled and meteorological conditions. The relative standard deviation ranged between 3.5% and 51.8% in the dual air samples.

The emission rates of VOCs were determined for 14 plant species within the Hobart Air Shed, using an enclosure bottle technique. In all, 284 compounds of 10 classes were detected. Emission rates varied between 1.98×10^{-8} and 5.43×10^{-6} g g^{-1} (wet weight) h^{-1} depending on the species sampled and prevailing conditions. The relative standard deviation was estimated to be 31.1%.

The VOC emission rate for the entire eucalypt forest in Tasmania was estimated as 8200 kg h^{-1} and for the Hobart Air Shed 59 kg h^{-1}. The error could be as large as a factor of three. The essential oil compositions of the species examined were identified. Linear relationships between VOC oil concentration and emission rates were found in 10 of the 13 analyses.

Key Words: Volatile organic compound (VOC), biogenic emission rate, enclosure, essential oil, biogenic hydrocarbons, monoterpenes, sesquiterpenes.

INTRODUCTION

The chemistry of the atmosphere is strongly influenced by the ecological processes that control the emission of water and trace gases from plants. Went (1960) recognised that emissions of volatile organic compounds (VOCs) from foliage could significantly affect tropospheric chemistry through the processes that form atmospheric haze. Large quantities of VOCs are introduced into the atmosphere by anthropogenic and natural sources. The natural sources are the marine and terrestrial environments; this study focuses on VOCs produced by vegetation — the principal emitter of natural VOCs, responsible for possibly two-thirds of global VOC emissions (Muller 1992). Interest in the emission of VOCs has escalated to gain a better understanding of their role in shaping global tropospheric chemistry, forming regional photochemical oxidants, balancing the global carbon cycle and producing organic acids that contribute to acidic deposition in rural areas (Fehsenfeld *et al.* 1992, Kesselmeier & Staudt 1999).

Plants produce a variety of organic molecules for biochemical purposes, emitting those that are volatile into the atmosphere. About 400 VOCs are known to be emitted by plants; most are C_{10}–C_{40} terpenoids (Hewitt & Street 1992), including aldehydes, ketones, organic acids, alcohols, alkanes, alkenes and the C_5 hemiterpene isoprene. There is a growing awareness that these compounds play an active role in the chemistry of the troposphere (Jacob & Wofsy 1988, Seeds 1999). Isoprene and the monoterpenes affect atmospheric chemistry processes (Guenther *et al.* 1991). Biosynthetic pathways have been outlined (Crouteau 1987, Kreuzwieser *et al.* 1999), but the exact functions of the VOCs are unclear. Some are believed to act as pollinator attractors, herbicides and pesticides, while others may simply be waste or by-products with no physiological role (Monson *et al.* 1995). Isoprene is thought to form as a means of losing surplus energy under high light conditions and during membrane stabilisation (Hewitt & Street 1992).

Given the number of plant species in the world, the available emission data of biogenic VOCs is sparse. Much of the work has been done in the Northern Hemisphere (Zimmerman 1979, Winer *et al.* 1992, Guenther *et al.* 1994, Andreani-Aksoyoglu & Keller 1995, Konig *et al.* 1995, Street *et al.* 1997, Arnold *et al.* 1998, Wedel *et al.* 1998, Gomez *et al.* 1999, Isidorov *et al.* 1999, Kesselmeier *et al.* 2000, Lindfors *et al.* 2000) and has focused primarily on the emission of isoprene and the monoterpenes (Konig *et al.* 1995, Loretto *et al.* 1996a, b, Staudt *et al.* 1997, Steinbrecher *et al.* 1997). The measurement of VOCs emitted by individual species and ambient air data in Australia are limited to marine baseline data collected at Cape Grim on the northwest coast of Tasmania (Galbally *et al.* 1994–1995), emissions of VOCs (primarily oxygenated species) by pasture (Kirstine *et al.* 1998), emissions from 15 *Eucalyptus* species (He *et al.* 2000a) and their seasonal variation (He *et al.* 2000b), and isoprene emission from

vegetation and hydrocarbon emissions from bushfires in tropical Australia (Ayers & Gillett 1988). This is the first study to assess the VOC emissions of the native plant species chosen and the first in Australia to determine terrestrial ambient air concentrations of a broad range of these VOCs.

Until recently, global emission inventories of biogenic VOCs have been based predominantly on the emission rates of deciduous and coniferous forest types in North America (Guenther *et al.* 1995), as experimental data from other parts of the world are lacking. The weakness of this approach was demonstrated by Hewitt & Street (1992) for the biogenic emissions of species in the United Kingdom. A global VOC emission database should ideally be set up on a genus level. The emission rates within a genus are similar and the use of genus emissions greatly simplifies modelling (Guenther 1997).

The National Pollutant Inventory Project was initiated in Australia on 1 July 1998 by Environment Australia. The nature of this project was to estimate the pollutants emitted into the air, land and water and compare this to the biogenic contribution of VOCs that take part in atmospheric processes such as the greenhouse effect and photochemical smog formation. The work described in this study relates to the determination of the nature, source and variation of biogenic VOCs in the Hobart Air Shed.

For the ambient air measurements, sites in the Hobart Air Shed with minimal anthropogenic VOC output were selected. One site (Chalet site) was sampled four times in three months April–June 2000, and other sites with different forest types were sampled. For the species enclosure measurements, species known to emit large quantities of VOCs were selected, together with the dominant species of the largest forest types in Tasmania. These include several eucalypt species other than *Eucalyptus globulus*, which has been studied elsewhere (Pio *et al.* 1997, Yassaa *et al.* 2000). The essential oils of these species were extracted by steam distillation and the compositions of the oils and emissions compared.

METHOD

Sampling Sites

Fifteen sampling trips were made to sites within the Hobart Air Shed in southern Tasmania (table 1). The GPS coordinates, time and environmental conditions for each sample were recorded (table 2). Supplementary weather conditions were obtained from the Bureau of Meteorology.

Apparatus

Air was sucked through adsorbent cartridges with a pump (Reciprotor, Type 506R) powered by a 430cca, 12-volt battery (Exide, model 430D) with a solid-state inverter. A displacement bottle method was used to measure the flow rate of air sucked through an adsorbent cartridge attached to the suction of the pump by polyethylene tubing. Typically 30 L of air were sampled for the ambient air experiments and 10 L for the enclosure experiments.

For most of the ambient air measurements, dual samples were taken using a Y-tube joiner and identical polyethylene tube lengths with an adsorbent cartridge attached to each. The flow rate of each sample was measured individually and the summed value was equivalent to the total flow generated by the pump showing that there were no pressure leaks in the system used. The samples were taken about 1 m above ground level.

For the enclosure measurements a 10 L glass bottle was used. Teflon bags have been used for inert sampling apparatuses, but they are expensive and present problems when sampling *in situ*. For the sampling of many individual species, the bottle seemed preferable, as it is rigid, portable and easily set up. The bottle had an 8-cm opening at the top where the branch of the plant being investigated entered the bottle and a 4-cm NS 23 ground-glass opening at the bottom where the NS 14/23 reducer was attached to a Schott Teflon-coated adjustable thermometer housing. This formed an airtight seal around the adsorbent cartridges. Care was taken to minimise handling the foliage and not damage the plant. Polyethylene plastic ensured an airtight seal around the top of the enclosure and the branch. Polyethylene tubing was attached to the pump and the cartridge. An adsorbent tube was placed in an airtight sheath made in the polyethylene plastic. The ambient air entering the apparatus was scrubbed with an adsorbent tube. To ensure that no ambient air was collected by the second adsorbent cartridge, the system was flushed by three volumes of the enclosure bottle (30 L) before the second adsorbent tube was put into place.

Adsorbent Cartridges

The glass cartridges were 78.6 mm long, 6.0 mm in external diameter and 3.0 mm in internal diameter. A restriction was placed in the glass cartridge to stop the pump removing the packing. Each cartridge typically contained 0.02 g of Carbosieve S-III 60/80 mesh and 0.10 g of Tenax TA 60/80 mesh purchased from Supelco. Glass wool was used to

TABLE 1
Coordinates of the sampling sites as measured by a Global Positioning System (GPS) and the altitudes as taken from topographical maps

	Howrah	Rokeby Hills	Meehan Range	Chalet	Springs	Radford Track
Southern Coordinate	42°53.210'	42°53.543'	42°50.071'	42°53.333'	42°54.889'	42°54.927'
Eastern Coordinate	147°24.483'	147°25.048'	147°24.635'	147°14.179'	147°14.935'	147°15.577'
Altitude (m)	40	80	140	980	720	520

separate the adsorbent packing. Cartridges were cleaned for 40 min at 290°C with nitrogen gas flowing at a rate of 15 mL min^{-1}. Each cartridge was sealed with Swagelok stainless steel endcaps fitted with Teflon ferrules.

Analytical Procedures

The adsorbent cartridges were placed into the injector port of the gas chromatograph (GC) and fitted with a rubber o-ring to form an airtight seal. Water was removed from the sample by dry gas purging. The precolumn was placed in a liquid nitrogen cryotrap to focus the VOCs before separation on the HP–1 capillary column. The VOCs in the sample were identified by their mass spectra and their respective amounts calculated from the TIC integration counts and external standards. The GC was a Hewlett Packard 5890 Benchtop Gas Chromatograph and the detector a Hewlett Packard 5970 Series Mass Selective Detector.

The nitrogen flow rate was 4 mL min^{-1} for VOC separation. The detector and thermal desorption program were started manually when the precolumn was removed from the cryotrap after the desorption period had elapsed. The data system used was HP1034C MS Chemstation Software. The GC oven temperature program was initially 20°C, which increased by 6°C min^{-1} to 290°C. The MS was operated in the positive ion, electron impact, scanning mode from 35–400 AMU at intervals of 0.58 s with the electron multiplier at –1.8 kV. A splitless method was used to ensure all of the sample was counted by the detector. VOCs were identified with the aid of the commercial NIST and the in-house mass spectral libraries of the Central Science Laboratory.

Water Removal

A 60-cm, DB-1 phase (0.15 μ m film thickness) megabore precolumn, was attached to the HP–1 crosslinked methylsiloxane (0.52 μ m film thickness) column of 25 m length, 0.32 mm internal diameter. The precolumn was used to stop the liquid nitrogen cryotrap from damaging the HP–1 column and the wider bore reduced ice blockage when placed in the cryotrap. To remove water before thermal desorption, each sample was purged with nitrogen gas (10 psi, 30 mL min^{-1}) for three minutes at 99°C. This allowed the desorption of water only; small, volatile compounds such as propane were still detected in equal proportions in replicate studies.

Cryotrap Focusing of VOCs

The precolumn was placed in a liquid nitrogen cryotrap to focus the thermally desorbed sample. The cartridge in the injector port was desorbed at a temperature of 220°C for 15 min at a flow rate of 12 mL min^{-1}. The nitrogen flow was continually checked for ice blockage in the precolumn.

Controls, Breakthrough and Error

For the ambient air analysis, replicates were made by using two cartridges simultaneously. An adsorbent cartridge that had been treated in the same manner as those used for VOC collection was always carried with the experimental cartridges to act as the blank. For the enclosure experiments, replicates could not be performed simultaneously. However, the same species was analysed consecutively under similar conditions. Error was calculated on the total sample amount and also for the individual compounds. For the enclosure experiments, the control was a branch without foliage in the enclosure. Breakthrough volumes were monitored by placing two adsorbent cartridges in series indicating whether the VOC collection method was quantitative. A suburban air sample was taken to assess whether the VOCs from the naturally vegetated sites differed from those at a potentially polluted suburban site.

Plant Species

Fourteen of the most common species found in the dry sclerophyll, wet sclerophyll and subalpine regions that dominate the Tasmanian vegetation (Reid *et al.* 1999) were selected: *Eucalyptus leucoxylon, E. viminalis, E. johnstonii, Epacris impressa, Phebalium squameum, Tasmannia lanceolata, Olearia phlogopappa, Leptospermum lanigerum, Ozothamnus antennaria, Correa lawrenciana, Pomaderris apetala, Bedfordia salicina, Acacia dealbata* and *Zieria arborescens.* The samples, which were growing at the chosen sample sites within a 20 km radius of Hobart, Tasmania, were identified by the Tasmanian Herbarium.

Standards

An internal standard is the standard of choice for gas chromatography (Schomburg 1990). However, an external standard mixture made up at six concentrations covering the range of VOC concentrations that were present in the ambient air and enclosure measurements was used as it was not known which compounds would be present in the samples taken (possibly up to 100) and spiking internal standards onto the sorbent catridges was not practical. The standards are listed in table 3; the solvent was HPLC/GC grade *n*-hexane solution (Mallinckrodt, 95%).

The standard mixtures were analysed on the GC–MS each time the samples were run to eliminate error from fluctuation in the GC–MS response. The standard curves spanned the different response factors in this study. An average was taken of these responses for quantitative purposes and the associated error was noted. For separation, the GC–MS injector was kept at 260°C and the HP7673 autosampler was used to make a 10 μL injection. The temperature was held at 20°C for 3 min, then increased by 6°C min^{-1} to 135 °C, giving a total run time of 27.17 min. The nitrogen gas column flow used was 4.6 mL min^{-1}.

Essential Oil Analysis

The foliage used in the enclosure experiments was brought back to the laboratory, weighed and steam-distilled by Boland's (1991) method to obtain the essential oil. Distillation typically took between 24 and 48 h. After the organic phase was collected and dried, the dichloromethane was evaporated to leave the essential oil. The oil was diluted volumetrically in hexanes for analysis by GC–MS.

The injector was held at 220°C. The oven was held at

60°C for 2 min and then increased by 6°C min^{-1} to 240°C, at which point the rate was increased to 30°C min^{-1} until 290°C was reached. The total run time was 38.67 min. The nitrogen gas column flow used was 4.6 mL min^{-1}.

Solid-Phase Microextraction (SPME) Analysis

The 100micron 24-gauge polydimethylsiloxane SPME fibre purchased from Supelco was desorbed at 200°C on the GC–MS before sampling. The fibre was housed in an airtight sheath and exposed for two hours. It was then placed directly into the injector port at 200°C following Betts's (2000) method. The temperature program for the GC oven was 5°C for 3 min, increasing by 6°C min^{-1} to 280°C. This temperature was maintained for 5 min, giving a total run time of 53.83 min. The flow rate of the nitrogen gas column was 5 mL min^{-1}.

RESULTS AND DISCUSSION

Ambient Air Analysis

Table 2 shows the sampling dates, type, conditions and the total VOCs found in g L^{-1} and the error associated with these measurements for each site. The average deviations for all individual compounds in a particular sample were below 52%, some as low as 12.8%, showing reasonable reproduciblity keeping in mind the uncertainty involved in quantifying trace volatiles in the air. Similar methods in the literature reported errors typically between 40% and 80% (Guenther *et al.* 1996, Wedel *et al.* 1998), which is comparable to the error found in this study. The maximum deviation from the function used to describe the specific response of the detection system was 53%, but the error was typically much lower than this. This is thought to be the largest source of error involved in the experimental technique.

Trends and Variation in Ambient Air Results

The total VOC concentrations found are shown in table 2. Temperature is the main variable that influences emission of terpenes (Fehsenfeld *et al.* 1992). Some trends can be established from the data sampled over several months from the Chalet site. Figure 1 shows a relationship between temperature and VOC air concentration but no clear relationship between humidity and VOC air concentration.

The Chalet site was classified as a subalpine woodland dominated by species such as Tasmanian snow gum (*Eucalyptus coccifera*), urn gum (*E. urnigera*) and occasionally myrtle (*Nothofagus cunninghamii*) (Wellington Park Management Trust 1996) and various understorey species. The Springs site was classified as wet sclerophyll dominated by *E. johnstonii* and various understorey species (Reid *et al.* 1999). The Radford Track site was classified as a wet eucalypt forest dominated by *E. obliqua* and *E. regnans* and various understorey species (Reid *et al.* 1999). The Meehan Range and Rokeby Hill sites were both dry sclerophyll sites, dominated by *E. viminalis, E. obliqua, E. tenuiramis* and various understorey shrubs (Reid *et al.* 1999).

VOCs Detected at the Sampling Sites

A total of 129 VOCs were detected by comparing the mass spectra of the compounds separated by gas chromatography to known spectra in the mass spectral libraries. This included 11 National Pollutant Inventory compounds (DPIWE 1998) that are notifiable substances to the inventory as of 1 July 1998. However, many monoterpenes and sesquiterpenes cannot be identified with certainty from their mass spectra alone. Thus, the compounds other than those used as standards in table 3 are tentatively identified.

Compounds that were widely represented among the sites were acetophenone, piperitone, benzophenone, 6,10-dimethyl-5,9-undecadien-2-one, acetic acid, pentane, butane, isobutane, isopentane, undecane, hexadecane, pentadecane, nonane, decane, tridecane, tetradecane, nonadecane, dodecane, 2-undecen-2-ol, *p*-menth-2-en-1-ol, 2-decen-1-ol, cineole, benzaldehyde, octanal, nonanal, decanal, undecanal, 2-tridecenal, 1,2,3-trimethylbenzene, 1-ethyl-2-methylbenzene, benzene, toluene, xylene, naphthalene and cymene.

Isoprene is typically present in biogenic VOC samples in the literature. However, it was not observed in any of the air or enclosure measurements taken as part of this study. This may be because isoprene production requires several consecutive days of a threshold temperature (about 20°C) to start (Sharkey & Loretto 1993). The temperatures and light conditions during the course of this study were probably too low for isoprene synthesis to be detected. Other important trends observed were:

1. More monoterpenes were present at nightfall, which may reflect decreased winds, a decreased atmospheric mixing height or both, which has been observed previously.

2. The main biogenic VOCs found at most sample sites were those dominating the *Eucalyptus* essential oils (i.e. cineole, piperitone, *p*-menth-2-en-ol, cymene and 6,10 dimethyl-5,9-undecadiene-2-one) (Boland *et al.* 1991). The VOCs present in the largest concentrations were generally acetic acid, benzaldehyde, cymene, cineole, acetophenone, nonanal and decanal. Acetophenone and benzaldehyde are likely to be an artefact of the reaction of low molecular weight polymers and impurities in the Tenax with ozone (Cao & Hewitt 1994).

Individual Compound Concentration at the Chalet Site

The compounds present in all the Chalet samples were piperitone, cineole, nonanal, decanal, cymene and acetophenone. In three of the four samples *p*-menth-2-en-ol and *p*-menth-3-en-ol were also present. The concentration of these compounds was compared with respect to the temperature and humidity at the time sampled. Table 4 shows the variation with temperature. No relationship was found with humidity.

The VOCs increased their ambient air concentrations when the temperature increased, as shown in table 4. The R^2 values ranging from 0.67–0.99 indicate reasonable linear relationships, but some other non-linear function cannot be disproved. It was found that the Y-intercept, which represents the minimum temperature in degrees Celsius at which the compounds will be detected in the air, ranged between 6.6°C for acetophenone and 10°C for cymene.

TABLE 2

Sample dates, times, conditions and the total VOC concentrations in ambient air and the total VOC emission rates for the enclosure experiments, indicating the errors involved

DATE	SITE	SAMPLE	TIME	SPECIES	CONDITIONS	TEMPERATURE (°C)	WIND SPEED AND DIRECTION (MT. WELLINGTON KM/H)	RELATIVE HUMIDITY (MT. WELLINGTON, %)	WIND SPEED AND DIRECTION (HOBART, KM/H)	RELATIVE HUMIDITY (HOBART, %)	HOURS OF SUNSHINE (HOBART)	CLOUD COVER AT TIME OF SAMPLE (OKTA-MEASURED IN EIGHTS OF SKY COVERED)	TOTAL VOC (g/L) FOR AMBIENT AIR AND (g/L$_{(wet\ weight)}$) FOR ENCLOSURE EMISSION RATES	RELATIVE STANDARD DEVIATION - USING TOTAL VOC VALUES (%)	RELATIVE STANDARD DEVIATION - USING AVERAGE OF INDIVIDUAL COMPOUNDS (%)
13/4/00	Springs	air	1230-1500	-	sunny, no wind	17	15 NNW	73.5	13 ESE	53	8.9	1	$2.55x10^{-9}$		
7/4/04	Springs	air	1502-1645	-	cloudy, no wind	3-6	27 WNW	91	6 SSE	62	2.3	3	$5.89x10^{-10}$		
13/4/00	Chalet	air	1545-1700	-	twilight, little wind	12-13	13.5 NNW	67.75	13 SE	60	8.9	1	$2.07x\ 10^{-9}$		
25/4/00	Chalet	dual air	1322-1512	-	sunny, no wind	12-18	13 W	59.8	13 ESE	50	9.9	0	$2.09x10^{-9}$	3.5	12.8
6/12/04	Chalet	air	1115-1320	-	sunny, little wind	9-10	26.8 N	68.4	17.3 NNW	45.3	9	1	$1.22x10^{-9}$		
14/6/00	Chalet	dual air	1502-1548	-	diffuse sunlight, little wind,	6-10	34.2 SW	62	11 E	50	6.1	7	$4.43x10^{-10}$	41	28.5
28/5/00	Rokeby Hill	air	1502-1549	-	cloudy, raining, fading light	6-7	-	-	9 W	73	2.9	6	$3.04x10^{-9}$		
8/12/04	Rokeby Hill	dual air	1502-1550	-	overcast, good light, no wind	9-11	-	-	16.7 NNW	61.5	3.5	7	$2.32x10^{-9}$	34	42.5
27/7/00	Meehan Range	dual air	1502-1551	-	overcast, little breeze	8-10	-	-	12.5 N	58	4.2	6	$1.80x10^{-9}$	44	39.5
31/7/00	Radford Track	dual air	1502-1552	-	sunny/overcast, slight breeze	8-9	17 NNW	98.5	8 N	63.7	0.2	7	$492x10^{-10}$	19	51.8
21/5/00	Howrah	air	1620-1719	-	cloudy, windy, twilight	12-14	-	-	27.5 NW	54.5	2.1	7	$2.91x10^{-8}$		
6/12/04	Chalet	SPME	1115-1320	-	sunny,little wind	9-10	26.8 N	68.4	17.3 NNW	45.3	9	1	-		
21/5/00	Howrah	enclosure	1620-1720	*Eucalpytus leucoxylon*	cloudy, windy, twilight	12-14	-	-	27.5 NW	54.5	2.1	7	$3.57x10^{-8}$		
28/5/00	Rokeby Hill	enclosure	1608-1703	*Eucalyptus viminalis*	cloudy, raining, fading light	6-7	-	-	9 W	73	2.9	6	$2.35x10^{-8}$		
8/7/04	Springs	enclosure	1134-1225	*Eucalpytus johnstonii*	overcast/sunny, no wind	8-9	11.6 N	85.6	11 NW	71.5	3.5	6	$2.29x10^{-8}$		
28/5/00	Indoors	enclosure	2130-2238	blank	indoors	12	-	-	-	-	-	-	-		
28/5/00	Howrah	enclosure	2335-0039	*Eucalpytus leucoxylon*	night, no light, windy	6	-	-	22.5 WSW	56	-	0	$1.10x10^{-8}$		
7/4/04	Springs	enclosure	1502-1546	*Phebalium squameum*	cloudy, no wind	5-6	23 WSW	90	4 SSE	61	2.3	6	$2.13x10^{-8}$		
7/4/04	Springs	enclosure	1619-1645	*Epacris impressa*	cloudy, no wind	3	30 WSW	93	9 S	63	2.3	1	$3.37x10^{-9}$		
22/6/00	Chalet	enclosure	1215-1310	*Tasmannia lanceolata*	overcast, cloudy, little wind	8-9	23 WSW	89.5	9 NNW	61	2.9	6	$8.19x10^{-9}$	6.7	31.1
22/6/00	Chalet	enclosure	1310-1350	*Tasmannia lanceolata*	overcast, cloudy, little wind	6-7	31.5 WSW	94.5	17NNW	59.5	2.9	6	$8.99x10^{-9}$	6.7	31.1
28/6/00	Chalet	enclosure	1040-1122	*Olearia phlogopappa*	cloudy, no wind	6-8	31 WNW	84	17 NW	61	4	6	$2.32x10^{-7}$		
28/6/00	Chalet	enclosure	1145-1227	*Leptospermum lanigerum*	sunny/cloudy, no wind	7-8	31 WNW	85	15 NNW	60	4	7	$1.73x10^{-8}$		
28/6/00	Chalet	enclosure	1254-1338	*Ozothamnus antennaria*	cloudy, no wind	7-8	28 WNW	83	17 NNW	54	4	7	$6.42x10^{-9}$		
28/6/00	Chalet	enclosure	1355-1427	*Correa lawrenciana*	cloudy, no wind	6	30 NW	84	11 NNW	59	4	7	$1.31x10^{-7}$		
8/12/04	Rokeby Hill	enclosure	1751-1851	blank	twilight, no wind	8-9	-	-	7.5 W	69	3.5	7	-		
20/7/00	Radford Track	enclosure	1412-1504	*Pomaderris apetala*	drizzle, overcast, wind gusts	6-8	54.5 WNW	98	29.5 WNW	54	2.7	7	$1.36x10^{-8}$		
20/7/00	Radford Track	enclosure	1532-1620	*Bedfordia salicina*	overcast, drizzle, no wind	5-7	54.3 WNW	98	18 NW	60	2.7	7	$1.94x10^{-9}$		
21/7/00	Radford Track	enclosure	1319-1411	blank	sleet, little wind gusts, cloudy	3-6	42.1 NW	93	25 NW	67	0.6	5	-		
21/7/00	Radford Track	enclosure	1440-1522	*Acacia dealbata*	snow,little wind, poor light	1	39.5 NW	95	26 NW	69.5	0.6	6	$9.16x10^{-10}$		
31/7/00	Radford Track	enclosure	1513-1557	*Pomaderris apetala*	overcast, no wind	7	14 N	99	10 NE	69.5	0.2	8	$2.84x10^{-9}$		
31/7/00	Radford Track	enclosure	1613-1650	*Zieria arborescens*	overcast, no wind	8	20.5 N	98.5	12 SE	74.5	0.2	8	$2.68x10^{-8}$		

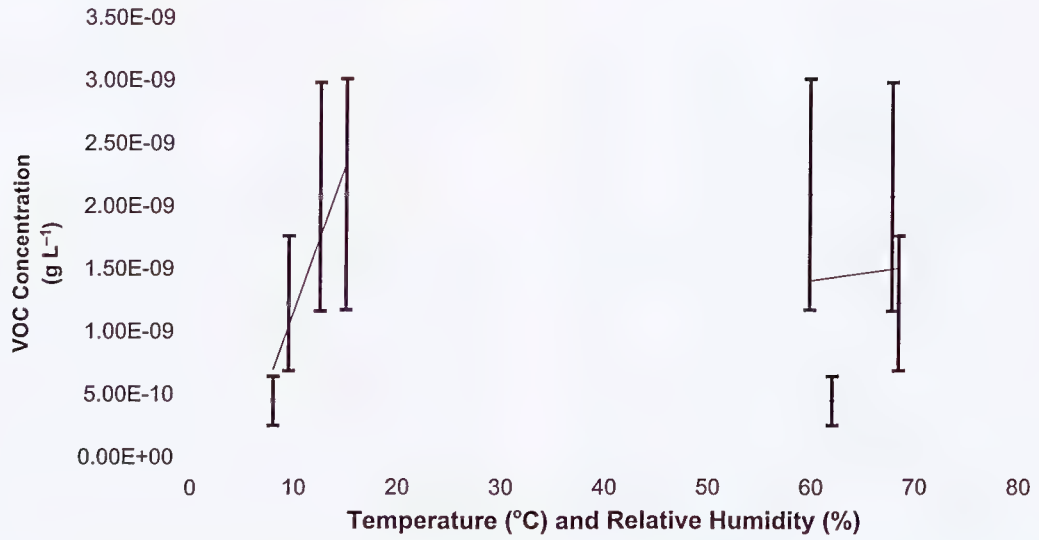

FIG. 1 — Variations of total VOC ambient air concentration (g L^{-1}) for temperature (left) and humidity (right). (A) The trendline for the temperature variation is represented by Y = (2 x 10^{-10}) x –(1 x 10^{-9}) with an R^2 value of 0.86.(B) The trendline for the humidity variation shows a poor fit with an R^2 value of 0.01.

TABLE 3
Standards used in this study

Reagent	Supplier	Grade	Reagent	Supplier	Grade
acetophenone	BDH	99%	a-pinene	Aldrich	98%
benzene	M and B	Distilled	limonene	Aldrich	96%
toluene	BDH	LR	propanal	Ajax	AR
xylene	BDH	99%	acetone	BDH	AR
geraniol	Koch Light	99%	1,8-cineole	Aldrich	95%
menthol	Hopkins and Williams	LR	heptane	Ajax	AR
p-cymene	Aldrich	99%	dodecane	Sigma	99%
ethyl acetate	BDH	AR	terpenen-4-ol	Fritzche-D and O	95%

TABLE 4
Graphical data found from VOCs ambient air concentration (g L^{-1}) at Chalet site vs temperature (°C)

Compound	Trendline equation Y =	R^2 value	Compound	Trendline equation Y =	R^2 value
acetophenone	(4 x 10^{-11}) x –(3 x 10^{-11})	0.74	cineole	(1 x 10^{-11}) x –(5 x 10^{-11})	0.67
decanal	(3 x 10^{-11}) x –(2 x 10^{-10})	0.80	*p*-menthen-3-ol	(8 x 10^{-12}) x –(5 x 10^{-11})	0.99
cymene	(2 x 10^{-11}) x –(7 x 10^{-11})	0.74	*p*-menthen-2-ol	(7 x 10^{-12}) x –(4 x 10^{-11})	0.63
nonanal	(2 x 10^{-11}) x –(2 x 10^{-10})	0.83	piperitone	(4 x 10^{-12}) x –(2 x 10^{-11})	0.69

The similarity of these trendlines may suggest that similar biological volatilisation mechanisms that govern the release of biogenic VOCs into the air and atmospheric degradation processes are occurring for a variety of different biogenic VOCs measured in this study.

Cymene, cineole, *p*-menthen-2-ol, *p*-menthen-3-ol and piperitone are all biogenic mevalonate metabolites produced by plants (Boland *et al.* 1991). Acetophenone is a shikimate metabolite produced by plants (Mann 1987) and has also been noted in the literature as an artefact (Cao & Hewitt 1994). Aldehydes such as nonanal and decanal were found in the oil analyses performed in this and other studies (Hendricks *et al.* 1978, Alonzo *et al.* 2000). Nonanal has been found in the emissions from slashed grass (Kirstine *et al.* 1998) and other species (Konig *et al.* 1995), but aldehydes were not found in the enclosure experiments in this study. Possibly aldehydes are emitted biogenically by species other than those sampled.

No anthropogenic compounds such as benzene or toluene (Pankow *et al.* 1998, Muraleedharan *et al.* 2000) were detectable in any of the air samples, so differences in variation between biogenic and anthropogenic compounds with regard to temperature could not be established. In future work, if the expected difference (Andreani-Aksoyoglu & Keller 1995) between biogenic and anthropogenic variation of compounds as a function of temperature is found, this could be used as a definitive means for establishing whether a given VOC is in fact of biogenic origin.

Compounds that were structurally similar tended to have similar trendlines, which is shown by nonanal and decanal, and *p*-menthen-2-ol and *p*-menthen-3-ol in table 4. This is a result of atmospheric lifetimes of the biogenic VOCs depending strongly on their structure.

The individual trends of increasing VOC air concentration with increasing temperature are in agreement with the total VOC trend for temperature at the Chalet site. The value for this trend was $Y = (2 \times 10^{-10}) \times -(1 \times 10^{-9})$ where the VOC air concentration is zero at 5°C (the Y-intercept). Note that the gradient for the total VOC should equal the sum of the individual gradients, as this represents the total VOC air concentration. The sum of the gradients for the compounds investigated is 1.4×10^{-10}, which is the major portion of the total VOC detected.

Use of Solid-Phase Microextraction for the Ambient Air Analysis of VOCs

Solid-phase microextraction has been used previously only for analysis of the headspace of a closed environment where the VOCs can accumulate and concentrations are much higher than those observed in the ambient air (Betts 2000). In this study the method proved to be too insensitive for analysis of ambient air VOCs. However, it might be a means of confirming the compounds present in enclosure measurements where the VOC concentrations are much greater.

Suburban Air Sample

The suburban air sample taken at Howrah showed that the alkanes, aldehydes and ketones present are probably not emitted from natural vegetation. This was taken into consideration in forming the subset of biogenic compounds in the air at the sample sites chosen. The suburban air sample had an abundance of straight-chain ketones, aldehydes and alkanes that were not found in any of the other samples. These may be due to pollutants in the case of the alkanes or to the introduced vegetation typical of suburban areas, including cut grass, which emits a variety of oxygenated VOCs (Kirstine *et al.* 1998).

Enclosure Air Analysis

The compounds tentatively identified by GC–MS were the terpenes α-pinene, myrcene, carene, camphene, a-phellandrene, 2,6,6-trimethylbicyclo(3.1.1.)hept-2-ene, limonene, longifolene, α-gurjunene, aromadendrene, alloaromadendrene, caryophyllene, α-copaene, β-cubebene, cymene and cineole. Sharkey & Loretto (1993) found that the capacity of isoprene emission disappears from leaves below 20°C and strong light is required for isoprene to be synthesised. Isoprene was not observed during the winter sampling period of this study (sample dates are given in table 2). Evans *et al.* (1982) reported that at 29°C, *Eucalyptus globulus* was the highest isoprene emitter of the 54 species studied; isoprene emission from eucalypts is therefore likely to be high during the summer months.

Quantification of Enclosure VOCs

Emission measurements can be affected by the handling of plants during enclosure sampling (Winer *et al.* 1992). Although care was taken not to stress the plant or damage its foliage, and every plant was given time to reach a steady-state in its enclosure environment, the enclosure emissions in this study must be regarded as estimates. Enclosure by the method chosen may incur an increase in emission rates, but this error is likely to be far outweighed by the error from scaling emission rates to larger biomasses. Similar compounds were observed from the same genus; for example, all eucalypts emitted cineole and aromadendrene as major components. The species enclosure emissions are summarised in table 5.

The highest emission rates were from the understorey species *Olearia phlogopappa* and *Correa lawrenciana*. Understorey plants, as well as the larger eucalypt trees that dominate Australian vegetation, make a large contribution to the VOCs emitted into the atmosphere.

The two *Tasmannia lanceolata* samples were quite close together, representing only a 6.7% total VOC deviation. Running these samples consecutively did not allow for large variations in sampling conditions; temperature changed by 2°C and other conditions remained fairly constant. The average individual compound deviation was 31.1%, indicating that the reproducibility was similar to the dual ambient air samples previously discussed.

Biomass Data to Form Estimates over Larger Areas

In the absence of species-specific biomass data, a collation of dry foliage biomass data from the literature (Cannell 1982) was used in conjunction with the averaged emission rates in this study to form an emission estimate. This allowed for the first time an estimate of the emission of total VOCs from the wet and dry sclerophyll forests of Tasmania. These results

TABLE 5
The quantification of the enclosure emissions by the species studied (HC = hydrocarbon)

Species	Total VOC emission ($g\ g^{-1}(ww)\ h^{-1}$)	Total HC monoterpene emission (%)	Total HC sesquiterpene emission (%)	Total oxygen-ated VOC emission (%)	Other emission (%)
E. leucoxylon (day)	4.53×10^{-7}	34	10	20	37
E. viminalis	3.03×10^{-7}	33	16	49	2
E. johnstonii	4.90×10^{-7}	4	3	68	25
E. leucoxylon (night)	2.00×10^{-7}	38	15	38	9
P. squameum	3.91×10^{-7}	76	20	1	3
E. impressa	4.75×10^{-8}	47	31	6	16
T. lanceolata	1.81×10^{-7}	44	12	21	23
T. lanceolata	1.84×10^{-7}	19	29	37	15
O. phlogopappa	5.43×10^{-6}	2	94	3	1
L. lanigerum	3.73×10^{-7}	26	24	40	10
O. antennaria	1.23×10^{-7}	4	12	43	42
C. lawrenciana	2.79×10^{-6}	53	46	1	1
B. salicina	3.61×10^{-8}	14	26	40	20
A. dealbata	1.98×10^{-8}	3	0	59	38
P. apetala	4.67×10^{-8}	53	5	14	27
Z. arborescens	3.67×10^{-7}	3	71	25	1

are shown in table 6. Foliage biomass variations between eucalypt species, as reported in the literature, was equivalent to the variations within a species when measured under different conditions, so it was considered reasonable to average these values and note the associated error as shown in table 7.

The average emission rate for the three species of eucalypt sampled was 1.3×10^{-7} g g^{-1} (wet weight) h^{-1} with a relative standard deviation of 37%. This compares well to the winter emission rates of different *Eucalyptus* species found by He *et al.* (2000). An average emission rate for the *Eucalyptus* species sampled under various conditions was estimated. These conditions include temperature variations between 6° and 14°C, relative humidity variations from 56% to 86% and sunshine variation due to night-time and daytime sampling. The average emission rate of the understorey shrubs, which showed greater variation due to the diffuse phylogenetic relationships between the species sampled, was 7.8×10^{-7} g g^{-1} (ww) h^{-1} with a relative standard deviation of 201%.

The standard deviations from the average foliage biomass and the average emission rates, together with the error arising from the sampling procedure already outlined, suggest that the error could be as great as 300% for the understorey emission estimates and 150% for the eucalypt emission estimates.

Relationships between Oil Concentration and Emission of VOCs

Because of the noted intra-species variation in the literature, the oil was isolated from the leaves of the plant sampled in the enclosure experiments (Boland *et al.* 1991). The composition of the oils of the following species have been identified in the literature: *Olearia phlogopappa* (Dragar *et al.* 1988), *Tasmannia lanceolata* (Southwell & Brophy 1992), *Eucalyptus viminalis* (Boland *et al.* 1991), *E. johnstonii* (Boland *et al.* 1991), *Phebalium squameum* (Ghisalberti 1998), *Leptospermum lanigerum* (Brophy *et al.* 1999) and *Zieria arborescens* (Flynn & Southwell 1987).

Of the 13 oil analyses of enclosure samples, 10 showed linear relationships that suggest emission rates can be estimated from the oil of some species if the environmental conditions are suitable. Different species would have different linear relationships between their oil component concentrations and the amount volatilised because of different oil gland abundances, sizes and leaf surface areas. The small number of VOCs that correlated in some of the essential oils and their emissions may explain why three analyses did not follow this trend. Some of the VOCs would have been below the detection limit of the GC–MS. Also, only the hydrocarbons and the smaller oxygenated hydrocarbons were observed in the enclosure emissions due to their higher volatilities than the other VOCs present in the oil.

The trendlines passed through the origin; table 8 lists the trends for the different species and the R^2 values. With greater concentrations for the oil compositions and larger air samples taken for the enclosure samples, the minor oil constituents would be included, which would give a better representation of the trends.

Our results conflict with those of Schindler & Kotzias (1989), who found no relationship between monoterpene volatilisation and leaf oil composition in conifers. This inconsistency may be due to the solvent extraction from charcoal method that they used for VOC trapping which had only an 85% recovery of emitted VOCs. Also, it is possible that the conifers have different biological mechanisms for releasing VOCs from their leaves as opposed to the species used in this study.

VOC emission appears to be limited by factors controlling the vapour-phase concentrations within the leaves, including liquid-phase concentration and vapour pressure (Evans *et al.* 1982). This helps to explain the inconsistencies found in this study. Hanover (1972) has shown a general correspondence between the volatiles present in oleoresin extracts and those present in the ambient air surrounding

TABLE 6
The emission of total VOCs from vegetative areas in kilograms per hour for eucalypts and understorey species in eucalypt forest

Vegetation type	Emissions of total VOCs from this vegetation (kg per hour)	
	eucalypts	understorey shrubs
Total dry sclerophyll in Tasmania	1200	4200
Total wet sclerophyll in Tasmania	600	2200
Total sclerophyll in Tasmania	1700	6400
Eucalyptus reserves in Hobart Air Shed	13	46
Total Tasmanian sclerophyll forest scaled down to Hobart Air Shed	16	59

TABLE 7
Average of foliage biomass and errors obtained from the literature for *Eucalyptus* species and the understorey shrubs of eucalypt forests

Vegetation type	Dry foliage biomass (t ha^{-1})	Number of experiments	Relative standard deviation
Eucalyptus species	4.9	32	49.7
Understorey shrubs	3.1	5	43.9

Pinus monticola. However, there were quantitative differences that appeared to be related to vapour-pressure differences.

Table 8 shows that the coefficients of the equations vary significantly. This value would vary within each species depending on the conditions. Further work is needed to elucidate the controls on the mechanism that manipulates the release of volatiles. The gradients were typically below unity, which may suggest mechanisms to conserve leaf oil were operating. Interspecies differences are attributable to the leaf's surface area to volume ratios and other physiological variations such as gland size, structure and the mechanism by which the plant regulates the passage of VOCs from within the oil glands to the atmosphere.

CONCLUSIONS

Ambient Air Analysis

- The typical components and concentrations of VOCs in six environments with minimal anthropogenic disturbance were found. Monoterpenes were the majority of the biogenic VOCs and isoprene was not found in the low-temperature ambient air samples taken.
- A positive correlation between VOC emission and air temperature was found. The characteristic emission factor was determined for the Chalet site. The functions describing the air concentrations of eight compounds at the Chalet site were found. The similarity of these functions may be typical of biogenic compounds in air.
- This study outlines the basal VOC air concentration taken over the winter months; samples taken over summer would complement these low-concentration data. As the main components in ambient air samples have been identified, standards could be prepared in future studies for the main VOCs present, reducing the error involved with the standard function used in this study.
- The solid-phase microextraction method used proved too insensitive for the ambient air analysis in this study. It could have future uses in enclosure studies where the concentrations are larger, or as a substitute for hydro-distillation in the analysis of VOCs in the leaves of plants.
- Suburban air contained many straight-chain alkanes, aldehydes and ketones, suggesting these are not biogenically produced or are from introduced species.

Enclosure and Oil Analyses

- The VOCs emitted from 13 Tasmanian native species and one introduced species (*Eucalyptus leucoxylon*) were ascertained and their emission rates determined.
- An emission estimate for the eucalypt forest in Tasmania and for the Hobart Air Shed indicated that understorey shrubs emit more VOCs than do the eucalypts.
- A general linear trend was found between the oil concentration and emission rates of plants, suggesting that emission rates might be predicted from the literature or hydro-distillation.

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TABLE 8
Suggested trends from oil/emission graphs for the species studied

Species	Equation of Trend Y =	R^2 Value	Number of data points	R^2 value suggests trend
O. phlogopappa	0.0492x	0.85	7	Yes
T. lanceolata	0.0059x	0.96	6	Yes
E. viminalis	0.0169x	0.82	11	Yes
E. johnstonnii	21.4x	1	6	Yes
Z. arborescens	0.0006x	0.75	7	Yes
P. apetala	0.289x	0.74	8	Yes
P. squameum	0.0348x	0.48	8	Yes
L. lanigerum	0.0699x	0.81	10	Yes
O. antennaria	0.0042x	0.00	4	No
A. dealbata	0.0037x	0.00	3	No
B. salicina	18.5x	1	3	Yes
C. lawrenciana	0.931x	0.90	13	Yes

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